# BIOGRAPHIES & ABSTRACTS

*International Conference on*

# WOOD ADHESIVES

September 28-30, 2009
Harveys Resort Hotel & Casino
Lake Tahoe, Nevada, USA

The conference is sponsored by the USDA Forest Service, Forest Products Laboratory, Forest Products Society, Georgia-Pacific Chemicals, LLC (Gold Level – Luncheon Sponsor), and Henkel Corporation (Silver Level – Continental Breakfast Sponsor).

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# PLANNING COMMITTEE

## CONFERENCE CHAIRS

Charles R. Frihart, Head of Wood Adhesives Science & Technology, Performance Enhanced Biopolymers, USDA Forest Products Laboratory, Madison, Wisconsin, USA

**Biography:** Dr. Charles R. Frihart is Head of Wood Adhesives Science & Technology, Performance Enhanced Biopolymers, USDA Forest Products Laboratory, Madison, Wisconsin. His responsibilities include technical lead on wood adhesive research at the Forest Products Laboratory. The research involves both fundamental science on wood adhesive interactions and development of new protein-based wood adhesives. He has been leading this area of research since 2001. Previously, he was Principal Scientist, Cognis Corporation; and Scientist, Senior Scientist, Group Leader, and Research Associate, Union Camp Corporation. He received a B.S. from the University of Wisconsin-Madison, and M.S. and Ph.D. from the University of Illinois.

Christopher G. Hunt, Research Chemist, Performance Enhanced Biopolymers, USDA Forest Products Laboratory, Madison, Wisconsin, USA

**Biography**: Dr. Christopher G. Hunt is a Research Chemist in the Performance Enhanced Biopolymers Unit at the USDA Forest Products Laboratory, Madison, Wisconsin. His responsibilities include research on soy adhesives for wood-panel products in cooperation with Ashland-HRT; durability of adhesives and coatings on wood; and wood nanostructure and decay mechanisms. He received a Ph.D. in Analytical Chemistry from the University of Wisconsin-Madison.

Robert J. Moon, Materials Research Engineer, USDA Forest Products Laboratory, Madison, Wisconsin, USA and Adjunct Assistant Professor, Birck Nanotechnology Center and School of Materials Engineering, Purdue University, West Lafayette, Indiana, USA

**Biography**: Dr. Robert J. Moon is a Materials Research Engineer at the USDA Forest Products Laboratory, and Adjunct Assistant Professor, Birck Nanotechnology Center and School of Materials Engineering, Purdue University. His responsibilities include leading a collaborative research program between Purdue University and the Forest Products Laboratory that advances nanoscale science and engineering of forestry-based materials. Research programs are being initiated in cellulose nanocrystalline technology, sensor technology, coatings technology, predictive modeling, and nanoscale characterization technique development. He received a B.S. in Metallurgical Engineering from the University of Wisconsin-Madison, and an M.S. in Metallurgical Engineering and Ph.D. in Materials Engineering from Purdue University.

## PLANNING COMMITTEE MEMBERS AND SESSION MODERATORS

Anthony (Tony) J. Allen, Senior Research Scientist, Ashland-Hercules Water Technologies, Madison, Wisconsin, USA

**Biography:** Dr. Anthony (Tony) J. Allen is a Senior Research Scientist at Ashland-Hercules Water Technologies, Madison, Wisconsin. He is the lead investigator for soy adhesives used in hardwood plywood and engineered wood flooring. He received a B.S. Chemistry and Ph.D. in Polymer Science from the University of Akron.

Stefan A. Bergmann, Executive Vice President, Forest Products Society, Madison, Wisconsin, USA

**Biography**: Stefan A. Bergmann currently serves as Executive Vice President of the Forest Products Society. Stefan has 7 years of non-profit association experience related to forestry and forest product issues at the national level, as well as in the northeast and midwest regions. In Washington, D.C., he worked on policy issues for the National Association of State Foresters. Following that, he served as the first staff for the Northeastern Area Association of State Foresters. He also has work experience in forestry extension and outreach at the University of Wisconsin-Madison. Most recently, Stefan served as Executive Director of the Great Lakes Forest Alliance, an international organization that facilitates cooperative efforts to enhance management and sustainable use of forest lands in the three Lake States and the Canadian province of Ontario. He holds an M.S. in Forest Resources from Oregon State University.

Bruce M. Broline, Principal, Broline Consulting, LLC, Pleasant Hill, Oregon, USA

**Biography:** Dr. Bruce M. Broline is a consultant in the wood adhesives and R&D management areas. He received a B.S. in Chemistry and an M.S. in Organic Chemistry from California State University-Hayward, and a Ph.D. in Physical Organic Chemistry from the University of Oregon. He has 20 years experience in construction adhesive R&D and 15 years experience managing R&D efforts for Neste Resins, Dynea, and Arclin. Prior to this, he worked for Boeing as a Senior Organic Chemist and Propulsion Analyst. He is a member of the American Chemical Society and the Forest Products Society.

Nicole R. Brown, Associate Professor of Wood Chemistry, Penn State University, University Park, Pennsylvania, USA

**Biography:** Dr. Nicole R. Brown is an Associate Professor of Wood Chemistry at Penn State University. Her responsibilities include research and teaching. Her areas of interest include adhesives; wood composites; cellulosic materials, bacterial cellulose, polymer science; chemistry of wood biopolymers; and other chemical treatments of wood. Previously, she was a Graduate Research Assistant, Virginia Tech. She received a B.S. in Forestry & Wildlife, and Ph.D. in Forest Products from Virginia Tech.

Zhiyong Cai, Project Leader, Engineered Composite Science, USDA Forest Products Laboratory, Madison, Wisconsin, USA

**Biography:** Dr. Zhiyong Cai is Project Leader of Engineered Composite Science at the USDA Forest Products Laboratory in Madison, Wisconsin. His responsibilities include: develop and supervise a broad basic research program that encompasses defining properties, surface modification, and protection of bio-based composite materials; and keep abreast of current literature and ensure that the latest scientific advances in wood- and bio-based composite technology, especially nanocomposites, are incorporated into the Unit's research and that the research is in concert with the U.S. Forest Service and National objectives and industry needs. His research interests include new product development, process evaluation and improvement, and forest sustainability. He received a Ph.D. in Wood Science & Engineering from Purdue University.

Chunping Dai, Senior Scientist and Group Leader, FPInnovations – Forintek Division, Vancouver, British Columbia, Canada

**Biography:** Dr. Chunping Dai is a Senior Scientist and Group Leader at FPInnovations – Forintek Division. He is responsible for setting the research priorities and directing the research program for the composites group in FPInnovations' Vancouver laboratory. He is also a project leader for veneer and strand-based composite products. Previously, he was a Research Scientist, Forintek Canada Corporation; and Research Scientist and Adjunct Professor, Wood Science & Technology Centre, University of New Brunswick. He received a B.S. in Wood Processing and M.S. in Forest Engineering from Nanjing Forestry University, and Ph.D. in Wood Science from the University of British Columbia.

Manfred Dunky, Manager, Research & Application Technology, Kronospan GmbH, Lampertswalde, Germany and Lecturer, Wood-Based Panels & Adhesives, Inst. of Wood Science & Technology, University of Natural Resources & Applied Life Sciences, Vienna, Austria

**Biography:** Dr. Manfred Dunky is Manager of Research & Application Technology including dissemination of knowledge and technology within the global Kronospan and KronoChem group. Previously, he was Technical Service & Application Manager, Dynea Austria. He received a Diploma for Plastics Technology and Dr.mont from the University of Leoben, and a Inauguration (Dozent) from the University of Natural Resources & Applied Life Sciences (BOKU).

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

**Biography:** Dr. Charles E. Frazier is a T.M. Brooks Professor of Wood Science & Forest Products at Virginia Tech and Director of the Wood-Based Composites Center. His responsibilities include instruction and research in wood adhesion and wood materials science. He received a B.S. from Virginia Tech, M.S. from the University of Washington, and Ph.D. from Virginia Tech.

Douglas J. Gardner, Professor and Program Leader of Wood Science, School of Forest Resources and AEWC Advanced Structures & Composites Center, University of Maine, Orono, Maine, USA

**Biography:** Dr. Douglas J. Gardner is Professor and Program Leader of Wood Science in the School of Forest Resources and the AEWC Advanced Structures and Composites Center at the University of Maine. His 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 cellulose nanocomposites. He has coauthored over 120 technical publications and 100 research presentations. Dr. Gardner is Past President of the Society of Wood Science & Technology. He is also a member of the Adhesion Society, American Chemical Society, and Forest Products Society. 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 the 2004-2005 G. Peirce and Florence Pitts Weber Outstanding Researcher in Forest Resources Award, the 2007 Director's Outstanding Faculty Award at the AEWC Center (University of Maine), and the 2008 Forest Products Society L. J. Markwardt Wood Engineering Award. He appeared in Strathmore's Who's Who 2007-2008. In December 2005, he was a visiting lecturer at Beijing Forestry University, and in June 2006 was a visiting lecturer at BOKU (Vienna, Austria). He was made an Honorary Member of the Union of Wood Processing Manufacturers of the Slovak Republic in 2000. He received a B.S. in Forestry (1980) and Certificate of Advanced Study in Pulp & Paper Management (1981) from the University of Maine, and a Ph.D. from Mississippi State University (1985).

Warren J. Grigsby, Scientist, Scion, Rotorua, New Zealand

**Biography:** Dr. Warren J. Grigsby is a Scientist at Scion in Rotorua, New Zealand. His research spans 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. 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 woodfiber products. Through his role, he takes a lead in the direction and coordination of innovative research efforts as well as industry liaison on both commercial and government-funded research. He has been with Scion since 1997 (previously named New Zealand Forest Research Institute) and has a previous background in organic, main group and transition metal-based synthetic chemistry and macromolecular chemistry. Previously, he was a Post-Doctoral Fellow, Monash University; and Post-Doctoral Researcher, University of California, Davis. He received a Ph.D. from the University of Waikato.

David P. Harper, Assistant Professor, Forest Products Center, University of Tennessee, Knoxville Tennessee, USA

**Biography:** Dr. David P. Harper is an Assistant Professor with a research appointment in the Tennessee Agriculture Experiment Station. He has been an active member of the Forestry, Wildlife & Fisheries faculty since 2004. Dr. Harper received a B.A. in Physics from West Virginia University before transferring to Washington State University in 1996. He then received an M.S. in Civil Engineering in 1998. Dr. Harper went on to receive his Ph.D. in Civil Engineering from Washington State University in 2003. In 2003, he conducted post-doctoral research at the U.S. Forest Service's Forest Products Laboratory in Madison, Wisconsin. Currently, Dr. Harper's work focuses on developing high-value products to serve as revenue streams for an integrated biorefinery and the forest products industry.

Philip E. Humphrey, Chief Science Officer, Adhesive Evaluation Systems, Inc., Corvallis, Oregon, USA

**Biography:** Dr. Philip E. Humphrey is Chief Science Officer at Adhesive Evaluation Systems, Inc. in Corvallis, Oregon. His responsibilities include conducting research and development in the fields of adhesion, thermodynamics and micro-mechanics of engineering composite materials; conceptualize and develop instrumentation to serve the bio-medical, aerospace, oil exploration, and building structures sectors; and coordinate socially relevant activities in developing countries. Previously, he was a Faculty member, Oregon State University; Faculty member, Cambridge University; and Materials Scientist, British Petroleum. He received a Ph.D. from the University of Wales.

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

**Biography:** Dr. Fred A. Kamke's research specialization is heat and mass transfer in wood and wood-based products, with emphasis on adhesion science, modeling, and the manufacture and performance of wood-based composite materials. He is the author of over 200 technical publications and presentations. Dr. Kamke has had primary responsibility for approximately $6 million in extramural research grants and contracts. He has taught college level courses in physical and mechanical properties of wood, wood anatomy, wood-based composite manufacture, drying of wood, wood and water relationships, durability of wood products, and adhesion of wood. Dr. Kamke also regularly teaches short courses developed for the wood-based composites industry. He is actively engaged in consulting activities in the areas of his research specialization. Dr. Kamke is a Fellow in the International Academy of Wood Science and a Past President of the Society for Wood Science & Technology. He received a B.S. from the University of Minnesota, and a Ph.D. Oregon State University.

Winford (Terry) T. Liles, Director of Adhesives Technology, Huber Engineered Woods, Commerce, Georgia, USA

**Biography:** Dr. Terry Liles is the Director of Adhesives Technology at Huber Engineered Woods, Commerce, Georgia. He is responsible for technical evaluation and approval of all non-wood raw materials used at all of Huber Engineered Woods locations, and lead project to develop and discover innovative materials that can be used in their product to enhance performance or improve cost position. Previously, he was R&D Group Leader, Georgia-Pacific Chemicals; and Senior Chemist, BASF Corporation. He received a B.S. from the University of South Alabama, and Ph.D. from University of Southern Mississippi.

Joseph J. Marcinko, Principal Scientist, Advanced Biopolymer Technologies, Mantua, New Jersey, USA

**Biography:** Dr. Joseph J. Marcinko is a Principal Scientist with Advanced Biopolymer Technologies. He is also Principal Scientist and founder of Polymer Synergies LLC. Dr. Marcinko has over 25 years of industrial R&D, research management, and academic experience. His interest and expertise are in the areas of polyurethane chemistry, biopolymers, adhesion science, composite materials, polymer characterization, solid-state NMR spectroscopy, and polymer structure-property relationships. He is an Adjunct Professor at Cumberland County College where he teaches Physical Science, Environmental Science, and Principles of Science. He also holds a secondary education teaching certification. Dr. Marcinko has authored over 30 publications, and has 4 patents, plus 7 patents pending. He received a Pennsylvania Professional Teaching Certification, B.S. in Chemistry, and B.S. in Biology from King's College; M.S. in Chemistry from Case Western Reserve University; and Ph.D. in Chemistry from the University of Akron.

Richard M. Rammon, R&D Program Manager, Georgia-Pacific Chemicals, LLC, Decatur, Georgia, USA

**Biography:** Dr. Richard M. Rammon is R&D Program Manager at Georgia-Pacific Chemicals, LLC in Decatur, Georgia. His responsibilities include management and oversight of Innovation efforts including major new product development projects and management of research portfolio, project prioritization, and resource allocation. Previously, he was R&D Manager/Facility Manager and Research Chemist, Georgia-Pacific Resins; and Development Chemist, Chembond. He received an M.S. in Wood Chemistry from the University of Wisconsin-Madison, and a Ph.D. in Material Science Engineering from Washington State University.

Klaus Richter, Head, Wood Laboratory, Empa – Swiss Federal Laboratories of Materials Testing & Research, Dübendorf/Zürich, Switzerland

**Biography:** Dr. Klaus Richter is a Wood Scientist and Head of the Wood Laboratory, Swiss Federal Laboratories of Material Testing & Research (Empa), Dübendorf/Zürich, Switzerland. He graduated from the University of Hamburg in 1983. During his Ph.D. program, he spent 2 years at the Iberian Peninsula where he collaborated, among others, with the 'Instituto de Maderas del INIA' in Madrid. After defending his Ph.D. thesis at the University of Hamburg, he joined the Wood Lab of Empa in 1987 as a Research Scientist. He is involved in research and development and testing activities and knowledge transfer in the fields of wood technology and wood products application in building and construction, wood adhesion, surface treatment, timber modification, wood-polymer interaction, life-cycle assessment of building materials, and sustainability in building and construction. He was elected as Head of the Lab in 2003 and holds teaching assignments at the Technical Universities of Zürich (ETH Zürich) and Graz (TU Graz).

Robert G. Schmidt, Senior Vice President, Research & Technology, Arclin, Mississauga, Ontario, Canada

**Biography:** Dr. Robert G. Schmidt is Senior Vice President, Research & Technology, Arclin, Mississauga, Ontario, Canada. He is responsible for all new product/process development and longer term research projects for Arclin North America. He received a B.S. in Forestry from the University of Toronto, Ph.D. from Virginia Tech, Master of Business Administration from Queen's University, and Certified Management Accountant Designation from the Society of Management Accountants of Ontario.

Kay-Uwe Schober, Professor of Timber Engineering & Structural Design, Mainz University of Applied Sciences, Mainz, Germany

**Biography:** Dr. Kay-Uwe Schober is a Professor of Timber Engineering & Structural Design at Mainz University of Applied Sciences, Mainz, Germany. He is also Owner of Planungsbüro Schober, Architects & Civil Engineers. Previously, he was a University Assistant in Structural Design, Dortmund University of Technology; and Partner, Schober + Partner Architects. He received a Dipl.-Ing. from Dresden University of Technology, and Ph.D. from Bauhaus-University of Weimar.

Milan Sernek, Associate Professor, Dept. of Wood Science & Technology, University of Ljubljana, Ljubljana, Slovenia

**Biography:** Dr. Milan Sernek is an Associate Professor in the Department of Wood Science & Technology, University of Ljubljana, Ljubljana, Slovenia. He teaches courses on the subject of wood-based composites manufacture and wood adhesives. He has been working on several projects related to wood adhesives and adhesion, monitoring adhesive cure and bond strength development, and bonding of modified wood. Previously, he was an Assistant Professor, University of Ljubljana; Graduate Student, Virginia Tech; and Young Researcher, University of Ljubljana. He received a B.S. and M.S. from the University of Ljubljana, and a Ph.D. from Virginia Tech.

Magdalena Sterley, Researcher, SP Technical Research Inst. of Sweden, Stockholm, Sweden and Ph.D. Student, Växjö University, Växjö, Sweden

**Biography:** Magdalena Sterley is a Researcher at the SP Technical Research Institute of Sweden, Stockholm, Sweden. She is currently working on projects dealing with the mechanical properties of glue lines including fracture mechanics and is an expert in gluing technology related to wood products. Her special area of research is green gluing (i.e. gluing of undried wood, which is also the objective of her doctoral studies conducted at Växjö University). She also works with multivariate statistics (PLS partial least square regression) mainly connected with evaluation of NIR-spectra of wood and modified wood as well as transport of water in wood investigated with MRI technique. Previously, she was a Researcher, Trätek Swedish Institute for Wood Technology Research; Research Engineer, Research & Development Institute of Polish Railways; and Research Engineer, Institute of Industrial Chemistry. She received an M.S. from Warsaw University of Life Sciences, and Licentiate of Engineering from KTH Royal Institute of Technology.

Xiuzhi (Susan) Sun, Professor, Dept. of Grain Science & Industry, Kansas State University, Manhattan, Kansas, USA

**Biography:** Dr. Xiuzhi (Susan) Sun is a Professor of Grain Science & Industry at Kansas State University (KSU), and the Director of the Center for Bio-Based Polymers by Design at KSU. She received her Ph.D. in Agriculture & Biological Engineering (1993) from the University of Illinois at Urbana-Champaign, and did her Post-Doctoral training at Texas A&M University. Her research interests include plant proteins extraction and modification, polypeptides and protein nano structures and adhesion, bio-based latex adhesives, poly(lactic acids) and sugar-based thermoplastics compounding and synthesis, bio-nanocomposites, thermodynamics and rheological properties of bio-based polymers. She is the author and coauthor of 100+ peer reviewed journal articles and 6 patents issued and 3 patents pending. She is the coauthor of a book *Bio-Based Polymers and Composite* published by Elsevier in 2005. She is the Associate Editor of *Journal of Bio-Based Materials & Bioenergy* and *Journal of Cereal Chemistry*. She was an invited speaker for numerous scientific symposia and international conferences. Dr. Sun is a member of the AACC, BEPS, AAAS, ACS, ASBAE, AOCS, and The Scientific Research Society Sigma Xi. She is the recipient of Sigma Xi Outstanding Senior Scientist Award in 2007. She was appointed as the USDA National Research Initiative Technical Panel Manager of Bio-Based Products & Bioenergy for two years (2004 and 2005). She serves on the committee of the USDA multi-states project *Science and Engineering of Biorenewables and Bioeconomy*. She participates in national strategic research planning workshops and program review panels in bio-based materials and bioenergy areas for USDA, DOE, EPA, and NSF.

# TECHNICAL SESSIONS

## Monday Morning, September 28

## PLENARY SESSION

### Development and Application of Wood Adhesives in China

Jiyou Gu, Professor and Dean, College of Materials Science & Engineering, Northeast Forestry University, Harbin, P.R. China; Zhiyong Cai, Project Leader, Engineered Composite Science, USDA Forest Products Laboratory, Madison, Wisconsin, USA

**Biography:** Dr. Jiyou Gu is a Professor and Dean of the College of Materials Science & Engineering, Northeast Forestry University, Harbin, P.R. China. He is also Vice President of the Chinese Wood Composite & Adhesive Research Society. He is the author of 100+ publications and 12 patents related to wood adhesives and products. He received a Ph.D. from Kyushu University.

**Biography:** Dr. Zhiyong Cai is Project Leader of Engineered Composite Science at the USDA Forest Products Laboratory in Madison, Wisconsin. His responsibilities include: develop and supervise a broad basic research program that encompasses defining properties, surface modification, and protection of bio-based composite materials; and keep abreast of current literature and ensure that the latest scientific advances in wood- and bio-based composite technology, especially nanocomposites, are incorporated into the Unit's research and that the research is in concert with the U.S. Forest Service and National objectives and industry needs. His research interests include new product development, process evaluation and improvement, and forest sustainability. He received a Ph.D. in Wood Science & Engineering from Purdue University.

**Abstract:** The rapid economic development and growth has resulted in substantial increases in demand and consumption of bio-based composites in China. This provides a unique opportunity for developing wood adhesives. This study reviews research development and major accomplishments in the area of wood adhesive and technology in China in the past years. It also discusses the characteristics of Chinese wood adhesive supply and consumption. It is concluded that urea-formaldehyde resin is still the dominant wood adhesive with about 70% of total resin consumption in China. However, public health and environmental concerns require development of new safe and green resin systems. It is expected that the future research and development of wood adhesive in China will not only focus on performance improvement and cost reduction, but also need to address concerns of public interests such as utilization efficiency of resource, product sustainability, pollution control, green construction, and global climate change.

### State of the North American Wood Composites and Wood Adhesives Markets

Herbert J. Kennedy, Regional Sales Manager, Wood Adhesives, Georgia-Pacific Chemicals, LLC, Decatur, Georgia, USA

**Biography:** As Regional Sales Manager at Georgia-Pacific Chemicals, Herbert J. Kennedy is responsible for Wood Adhesives business/contract management and sales-team management for the Eastern portion of North America. Previously, he was Technical Service Manager, Wood Adhesives and Technical Sales, Wood Adhesives, Georgia-Pacific Chemicals, LLC; Technical Sales, Wood Adhesives, Borden (now Hexion) Chemical; and Technical Manager, Temple-Inland Particleboard. He received a B.S. in Wood Science from Auburn University.

**Abstract:** 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 gain market share vs. traditional products. The health and vitality of the wood composites and the wood adhesives industries are crucial to each other. The wood adhesives industry and the composite panel industry partner to adjust to a changing market place in North America. An overview of past and current composites use patterns as well as projections for the future is presented. The recent downturn in the building sector, and the economy as a whole, is discussed. Projections, from various sources, for economic conditions and demand for composites are presented and compared. Current demand and economic indicators are compared to past published projections and the discrepancies are discussed.

### North American Resin Suppliers' Green Perspectives

*Tom C. Ruffing*, Graduate Research Assistant, *Paul M. Smith*, Professor of Forest Products Marketing, and *Nicole R. Brown*, Associate Professor of Wood Chemistry, Penn State University, University Park, Pennsylvania, USA

**Biography:** Dr. Nicole R. Brown is an Associate Professor of Wood Chemistry at Penn State University. Her responsibilities include research and teaching. Her areas of interest include adhesives; wood composites; cellulosic materials, bacterial cellulose, polymer science; chemistry of wood biopolymers; and other chemical treatments of wood. Previously, she was a Graduate Research Assistant, Virginia Tech. She received a B.S. in Forestry & Wildlife, and Ph.D. in Forest Products from Virginia Tech.

**Abstract:** The North American interior wood composite panel (IWCP) industry, consisting of particleboard, medium density fiberboard, and hardwood plywood, is adapting to recently enacted regulations by the California Air Resources Board (CARB) regulating formaldehyde emissions from IWCP products. Since formaldehyde is commonly utilized as a crosslinking agent in IWCP resins, the CARB legislation – effective January 2009 – will drive changes within the North American IWCP resin industry. The North American IWCP resin industry is highly concentrated and has been dominated by urea-formaldehyde (UF) adhesives. A phone survey of North American resin suppliers was conducted in the fall of 2008 to better understand their product positioning and "green" resin development strategies within the context of the impending CARB regulations. Results of this exploratory study indicate that IWCP resin manufacturers primarily compete via a differentiation strategy for their products and/or services. Moreover, resin suppliers perceive the product and service attributes of greatest importance to their IWCP customers to include: low formaldehyde emissions from finished panel (4.9 out of 5); fast resolution of customer complaints (4.4); reduced VOC emissions during panel pressing (4.3); support during resin trials (4.3); and on-time delivery (4.2). Results also show the regulatory environment (CARB) as the number one factor driving IWCP resin suppliers' "green" resin programs. Findings suggest that the new formaldehyde emission standards implemented by CARB are having a profound affect on the business practices of North American IWCP resin suppliers.

### The CARB Rule: Driving Technology to Improve Public Health

*Jeffery R. Williams*, Air Pollution Specialist, California Air Resources Board, Sacramento, California, USA

**Biography:** Dr. Jeffery R. Williams is an Air Pollution Specialist with the California Air Resources Board, Sacramento, California. He is currently working on implementation of the Airborne Toxic Control Measure to Reduce Formaldehyde Emissions from Composite Wood Products. His responsibilities include evaluation of Third Party Certifiers, development of deconstructive test method for finished goods, development of field screening method, coordination of inter-laboratory comparison for Third Party Certifiers and contract labs. Previously, he was a Graduate Student and Post-Graduate Researcher, University of California, Davis. He received a B.S. and Ph.D. in Biochemistry & Molecular Biology from the University of California, Davis.

**Abstract:** While formaldehyde emissions from particleboard, medium density fiberboard, and hardwood plywood contribute substantially to an individual's total daily exposure and associated health effects, the only previous attempt to limit formaldehyde emissions from these products in the United States (U.S.) was the adoption of the U.S. Housing and Urban Development standards for mobile homes in 1985. In comparison, stringent formaldehyde emissions standards have been adopted in other parts of the world, including Europe and Japan, in recognition of the known public health effects of formaldehyde. In California, the state Health and Safety Code mandates the Air Resources Board to develop Airborne Toxic Control Measures to protect public health from airborne carcinogens such as formaldehyde. On April 26, 2007, ARB approved the Airborne Toxic Control Measure to Reduce Formaldehyde from Composite Wood Products (ATCM), the first phase of formaldehyde emission standards went into effect January 1, 2009. The phase 1 standards are of similar stringency to the European E1 standards, while the phase 2 standards are technology forcing and are comparable to the Japanese F*** and F**** standards. An overview of practical and technical aspects of the ATCM will be presented. Implementation of the third party certifier program, development and testing of screening methods, and incentives to move toward ultra low emitting or no added formaldehyde resins are also discussed.

## Monday Afternoon, September 28

## CONCURRENT SESSIONS

## SESSION 1A: Environmental

### Impact of Green Building on Wood Adhesives

*Ashlee T. Cribb*, Market Manager, Wood Adhesives, Georgia-Pacific Chemicals, LLC, Atlanta, Georgia, USA

**Biography:** Ashlee T. Cribb is Market Manager, Wood Adhesives at Georgia-Pacific Chemicals, LLC. She is responsible for development and implementation of segment market strategies for the Georgia-Pacific Wood Adhesives business, including new product development and growth opportunity identification. A member of the Georgia Chapter of the U.S. Green Building Council, she has been active during the past 4 years in developing market and product strategies for the green building market. Previously, she was Director of Marketing & Innovation, Imerys Minerals; Marketing Manager, Solutia; Marketing/Technical Service/Sales, Research Engineer, and Process Engineer, Monsanto. She received a Master of Business Administration from Washington University, and Bachelor of Chemical Engineering from Georgia Institute of Technology.

**Abstract:** An update on developments in green building standards and their impact on wood adhesives is presented. Requirements that relate to wood adhesives in the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED®) Green Building Rating System™, the Green Building Initiative® Green Globes™ rating system, and the National Association of Home Builders National Green Building Standard™ will be reviewed. These standards will be compared to regulatory requirements and the resulting implications will be explored. As a result of these voluntary and regulatory requirements, a number of new resin technologies have been developed, the demand for which will be explored through an overview of the market drivers associated with green building. In conclusion, the presentation will identify indicators that validate an emerging and growing demand of new wood adhesive types and composite wood products for the green building market. 1) Leadership in Energy and Environmental Design, LEED, and Green Building Rating System are trademarks of the U.S. Green Building Council. 2) Green Building Initiative and Green Globes are trademarks of The Green Building Initiative. 3) National Green Building Standard is a trademark of the National Association of Home Builders.

### CARB Formaldehyde Emission Standards: An International Perspective

*Tom C. Ruffing* and *Wenping Shi*, Graduate Research Assistants, *Nicole R. Brown*, Associate Professor of Wood Chemistry, and *Paul M. Smith*, Professor of Forest Products Marketing, Penn State University, University Park, Pennsylvania, USA

**Biography:** Tom C. Ruffing is a Graduate Research Assistant in the School of Forest Resources at Penn State University. He conducts scholarly research in the area of wood composite materials. Specific areas of research focus include formaldehyde emissions policy, formaldehyde emissions test methodology, wood adhesives marketing, and isocyanate adhesive applications. Previously, he was a Summer Intern, Bayer MaterialScience (2006, 2007). He received a B.S. in Wood Products from Penn State University.

**Abstract:** This paper presents an overview of the major domestic and international formaldehyde emission standards. Formaldehyde emission standards in Japan, China, Europe, and the United States will be addressed, with special emphasis on the newly enacted California Air Resources Board (CARB) standards. Product-specific emission limits, affected products, and a historical context for standard development will be included for each standard.

## Measurement of Significant Native Formaldehyde Generated During Wood Composite Panel Production

*Michael J. Birkeland*, R&D Project Manager, HRT-Ashland, Edgerton, Wisconsin, USA; *Charles R. Frihart*, Head of Wood Adhesives Science & Technology, Performance Enhanced Biopolymers, USDA Forest Products Laboratory, Madison, Wisconsin, USA; *James M. Wescott*, CTO and Technical Director-Wood Adhesives, HRT-Ashland, Waunakee, Wisconsin, USA; *Linda Lorenz*, Chemist, Performance Enhanced Biopolymers, USDA Forest Products Laboratory, Madison, Wisconsin, USA

**Biography:** Dr. Charles R. Frihart is Head of Wood Adhesives Science & Technology, Performance Enhanced Biopolymers, USDA Forest Products Laboratory, Madison, Wisconsin. His responsibilities include technical lead on wood adhesive research at the Forest Products Laboratory. The research involves both fundamental science on wood adhesive interactions and development of new protein-based wood adhesives. He has been leading this area of research since 2001. Previously, he was Principal Scientist, Cognis Corporation; and Scientist, Senior Scientist, Group Leader, and Research Associate, Union Camp Corporation. He received a B.S. from the University of Wisconsin-Madison, and M.S. and Ph.D. from the University of Illinois.

**Abstract:** Processing of wood, especially as in the production of wood composites, has been found to generate significant "native", wood-based formaldehyde, even in the presence of wood pressed using no adhesive. The level of native formaldehyde is directly related to the time and/or temperature of the hot pressing. The native formaldehyde decays in a relatively short time and is not part of the long-term formaldehyde emission issue. We show that the desiccator/chromotropic acid method used in this study distinctly measures formaldehyde and not other similar compounds. Furthermore, the use of no adhesive or a no-added formaldehyde (NAF) adhesive in making particleboard produced high native formaldehyde levels. Proper adhesives can suppress the native formaldehyde emissions, with soy-based adhesives providing low formaldehyde emission levels on both the short and long term. This work highlights an important, but often overlooked aspect that should be considered for emission testing; namely, standardizing the time and conditions employed immediately after pressing, but prior to the onset of the emissions testing.

## Reduction of Formaldehyde Emission from Particleboard Panels: Evidence for a Threshold Effect due to Remaining UF Resin

*Mark Irle*, Director of Research, *Christophe Belloncle*, Senior Researcher, and *Baha Guezguez*, Ph.D. Student, Ecole Supérieure du Bois, Nantes, France

**Biography:** Dr. Christophe Belloncle is a Senior Researcher at Ecole Supérieure du Bois in Nantes, France. His responsibilities include teaching chemistry and organic chemistry to master level students of the "Ecole Supérieure du Bois" (Academy of Wood Sciences – France), that include areas such as coating chemistry and processes and polymer chemistry. He is strongly involved in the SME's network as a consultant in wood coatings and VOC management and is responsible for all chemistry projects focusing on wood/wood-based materials and the way of increasing performance. He currently works with a team of two Ph.D. Students on the topics of adhesives/chemicals in recycled wood, and two new students will join the team in October to work on new topics such as wood energy and fire resistance. He was a member of the management committee of the COST Action "Wood Processing Strategy" (A European network) from 2004 to its end in 2008. Previously, he was Project Manager, ECOCHEM SARL; Project Manager, AIMCO SA; and Engineer and Ph.D. Student, University of Rennes. He received an M.S. in Organic Chemistry and Ph.D. in Chemistry from University of Rennes 1.

**Abstract:** The subject of this paper is the presentation of research performed during the studies on the reduction of formaldehyde emission from panels made with urea-formaldehyde-based adhesives. The project, called Eco-Panneaux, is being carried out by a research consortium of small- and medium-sized companies and technical institutions. Most of the work dealing with formaldehyde reduction is focusing on additives such as sequestrants, and non-emitting extenders that dilute the UF resin. In such cases, the panel mechanical properties are important indicators of the viability of the additive. Formaldehyde emission is only measured if the mechanical performance is adequate. In doing such work, formaldehyde measurements made following EN 717-2 (gas analysis method) provided some unexpected results. First results were obtained with particleboard panels made with natural non-emitting adhesives and wood particles from our partners. Higher than expected results of up to 4 mg/m$^2$/h were obtained. Panels made with pMDI gave similar results. Other panels were made from increasing ratio of wood coming from companies and virgin wood from our own grinder. Formaldehyde emission increased linearly with recycled wood content. An alternative set of panels were made with decreasing amounts of UF resin binder; the emission values do not decrease linearly with resin content, but remain almost constant over the range tested. This paper will show the different experiments and results in detail. A possible conclusion is that low quantities of UF glue coming from recycling wood-based panels can act as a reservoir, reducing efforts in finding solutions to decrease formaldehyde emission.

## Do Non-Formaldehyde Emitting Products Have to be Produced with Non-Formaldehyde Adhesives?

*Astrid Pedersen*, Product Development Manager, IWS, Dynea AS, Lillestrøm, Norway

**Biography:** Dr. Astrid Pedersen is Product Development Manager for Dynea's European group responsible for the development of adhesives for Interior Wood Solutions (IWS). IWS includes the following application areas: 1) Curved plywood – production of form pressed products used as furniture parts; 2) Flooring/parquet; 3) Solid wood lamination – production of solid wood panels for furniture or window frames; 4) Veneering – gluing of veneer on board materials for production of furniture; 5) Foil lamination – gluing of foil on board materials. She is responsible for development of the following types of adhesives/adhesive systems for the above mentioned applications: 1) Formaldehyde-based adhesives based on urea and/or melamine; 2) Hardeners (catalysts/curing agents) for formaldehyde-based adhesives; 3) PVAc adhesives; 4) EVA adhesives; and 5) EPi adhesives. She is also a member of Dynea's Core Team for the application area IWS. The Core Team is responsible for the strategy and all major decisions within IWS. Previously, she was Chief Research Chemist, Dynea AS; Senior Research Chemist II and later Senior Research Chemist I, Dyno As and Dynea AS; Section Head, Wood Glues, Dyno Singapore; and Research Chemist and later Senior Research Chemist II, Dyno AS. She received a Sivilingenioer (equivalent to Master of Science) from the University of Trondheim, and a Doctor of Science from the University of Oslo.

**Abstract:** The increased focus on the health risks of formaldehyde has resulted in changes in legislation and customer requirements. As many other suppliers of formaldehyde-based adhesives, Dynea has spent a great deal of resources on developing low emitting adhesive systems. The focus on formaldehyde is not new; over the last 20-30 years the adhesive industry has gradually reduced the formaldehyde content in the formaldehyde-based adhesives. With each reduction it becomes a greater and greater challenge to maintain the adhesive properties. With the latest legislations and customer requirements we are getting close to requiring no formaldehyde emission, except for what is normal for natural wood, from glued wooden product. Must we assume that only non-formaldehyde adhesives, such as PVAc, polyurethane, and EPI (Emulsion Polymer Isocyanate) adhesives, can realistically meet this goal? Dynea has developed a portfolio of formaldehyde-based adhesive systems that gives glued wooden products with formaldehyde emission on the same level as natural wood itself. Demanding products such as curved plywood (form pressed products), which normally cannot be produced with PVAc adhesives, can be produced without loss of adhesives properties, without changes in the production and without investments in equipment. This presentation will illustrate the results of our new Dynea AsWood™ technology, and how it exceeds current formaldehyde emission standards using normal gluing equipment.

## Production of Low Formaldehyde Emission UF Resins

*João Ferra*, Ph.D. Student, Laboratory of Process, Environment & Energy Engineering, FEUP-LEPAE, Porto, Portugal; *Jorge Martins*, Professor, Laboratory of Process, Environment & Energy Engineering, FEUP-LEPAE, Porto, Portugal and Dept. of Wood Engineering, Polytechnic Inst. of Viseu, Viseu, Portugal; *Adélio M. Mendes*, Professor, Laboratory of Process, Environment & Energy Engineering, FEUP-LEPAE, Porto, Portugal; *Mário R. Costa*, Professor, Laboratory of Separation & Reaction Engineering, LSRE, Porto, Portugal; *Luisa H. Carvalho*, Professor, Laboratory of Process, Environment & Energy Engineering, FEUP-LEPAE, Porto, Portugal and Dept. of Wood Engineering, Polytechnic Inst. of Viseu, Viseu, Portugal; *Fernão D. Magalhães*, Professor, Laboratory of Process, Environment & Energy Engineering, FEUP-LEPAE, Porto, Portugal

**Biography:** João Ferra obtained a degree in Chemical Engineering from the Faculty of Engineering of the University of Porto (FEUP), Portugal in 2005. He was an Erasmus Student at the Higher Technical Engineering School, University of Santiago de Compostela, Spain, between February and July 2005, having worked on a research project titled "Osmotic dehydration of chestnuts in a watery middle with agitation." He has been a Ph.D. Student at FEUP since 2006. His Ph.D. work is subordinated to the theme "Optimization of UF resins for the production of composites made with wood from different species/origins." The last 3 years, he has presented some works in congress related to adhesives for wood (IPPS 2007 and 2009; ECOWOOD 2008).

**Abstract:** In the near future, companies will face the need to produce low formaldehyde emission resins, not above the emission level of natural wood. The main chemical and/or health organizations have reevaluated the acceptable levels of formaldehyde emissions and more restringing rules have been imposed by authorities. The International Agency for Research on Cancer has included formaldehyde in Group 1 ("there is sufficient evidence in humans & animals for the carcinogenity of formaldehyde"). The main changes on UF resins formulations have been driven towards decreasing the molar ratio of formaldehyde to urea. However, this worsens the mechanical properties of particleboard and additionally increases the time required for hardening under the action of commonly used hardeners. So, it is necessary to optimize the synthesis of UF resins, changing the production process. This work describes a study with the goal of optimizing and developing new processes for UF resins synthesis. We have investigated the effect of the kinetics, namely the order of the methylolation and condensation step, on resin performance. The results obtained so far have shown that the sequential addition of urea (U) played a significant role in increasing the Internal Bonding (IB) and reducing the Formaldehyde Emission (FE), but the acidification pH is also an important factor for the reduction of the formaldehyde emission.

### AsWood™ – Technologies for Composite Boards with Formaldehyde Emissions as Defined by Nature

Kristina Đurkic, Research Manager, and *José Gomez-Bueso*, Chief Scientist, Dynea AS, Lillestrøm, Norway; *Elke Fliedner*, Senior Chemist, Dynea Erkner GmbH, Erkner, Germany

**Biography:** Kristina Đurkic is Head of the Research Group at Dynea AS in Lillestrøm, Norway. She is responsible for the group of chemists, engineers, and lab technicians mainly working on projects related to Composite boards. As Project Leader, she is responsible for coordination of the scientists and project members, as well as the external partners in the projects and for the project funding and IP within the projects. She is also responsible for the transfer of Research findings into the commercial part of the company. Previously, she was Senior Researcher II, R&D Panelboard Resins Dynea Europe and Research Chemist, R&D Panelboard Resins Dynea Europe, Dynea Norway; and Research Chemist, Global R&D for Industrial & Composite Board Resins, Dyno Norway. She received a Bachelor degree from the University of Zagreb, M.S. from the University of Bergen, and Bachelor Program degree in Project Management from B.I., Norwegian School of Management.

**Abstract:** In the last decades, awareness of our well-being and as of human influence on nature has become one of the main concerns of today's society. The Chemical industry and its customers within the woodworking industry have always been challenged about their impact on health and the environment. Pressure from either the authorities or public opinion has led industry to strive to improve the working environment and product quality. Consequently, restrictions on formaldehyde emissions are constantly becoming stricter, with the question arising at the same time as to where the final, safe limit is. Solving emission issues has brought industry the challenge of balancing the relationship between product performance and economical feasibility. Factors such as more expensive or scarce raw materials, energy costs, production time, off-spec production and external formaldehyde certification make it more complicated for achieving effective profitable production at the required quality. Dynea's solution to those challenges is a technology developed for the production of composite boards with formaldehyde emission at the emission level of natural wood, namely AsWood™. AsWood™ technologies are a family of adhesives systems that cure to a hydrolytically stable and non-formaldehyde emitting polymer network. Part of the adhesive system is a specially developed accelerator to secure economically competitive production and to maintain the mechanical properties of the AsWood™ panels. Applications in industrial and pilot scale installations and a comparison with traditional low-formaldehyde emitting or non-formaldehyde technologies show the uniqueness of AsWood™ in emission performance.

## SESSION 1B: Applications 1

### Ultra Fast Structural 2K Adhesives: Continuous Manufacturing and Economical Production with Lot Size One

*Willi Schwotzer*, CTO, *Hans Peter Luthiger*, Project Leader, *Patrick Steiner*, Technology Manager, and *Sebastian Meyer*, Application Engineer, Nolax AG, Sempach Station, Switzerland

**Biography:** Dr. Willi Schwotzer is the Chief Technology Officer at Nolax AG in Sempach Station, Switzerland. His responsibilities include representing the company in technology issues; networking with academic world; networking with industry; and management of Intellectual Property. Previously, he was Manager, Technology, Collano AG; Executive Vice President, Ebnother AG; Manufacturing Manager, Polymer Powders, Elotex AG; and Senior Research Scientist, Texas A&M University. He received a Diploma in Chemistry and Doctor of Science from Zürich University.

**Abstract:** Modern assembly lines are fast, efficient, and characterized by high process reliability. Structural adhesives employed in such lines can be a point of concern as their curing time often determines the speed of the entire process. The use of catalysts may help to alleviate the problem, but imposes strict requirements for both the metering and the activity of the catalyst. Autocatalytic systems, viz., systems in which one of the main components acts as a self-contained catalyst, are kinetically more robust as they operate on a kinetic plateau of maximum velocity. The chemical reaction which leads to the formation of polyureas is an example of such auto catalyzed systems. The polymer is known in the industry to form tough coatings with excellent resistance against chemical and environmental influences. We therefore explored its potential use as an adhesive for a manifold of substrates such as metals, glass, wood, ceramics, etc. We thereby found a plethora of formulations suitable for almost every purpose. Aromatic and aliphatic systems are equally suitable which grants a high degree of freedom to the formulator. The wood processing industry appears to be a very attractive field of application for such systems for two main reasons: 1) The high reaction rates allow for a continuous manufacturing of wood elements such as prefinished parquet, wood plates, beams, etc. 2) The fast continuous manufacturing allows for a lot size of 1 thereby reducing stock and enhancing production flexibility. Since traditional production equipment is not suitable for such fast adhesive systems, new manufacturing concepts and tools have to be developed. In the proposed paper, we shall summarize the principles of polyurea-based adhesives and present examples of applications and application equipment.

### Ultrasonic Atomization of Resins for Bio-Based Composites Industry: Opportunities, Challenges, and Limitations

Lech Muszynski, Assistant Professor, Dept. of Wood Science & Engineering, Oregon State University, Corvallis, Oregon, USA; *Douglas J. Gardner*, Professor and Program Leader of Wood Science, School of Forest Resources and AEWC Advanced Structures & Composites Center, University of Maine, Orono, Maine, USA; *Xuelian Zhang*, Post-Doctoral Research Associate, School of Forest Resources, Penn State University, University Park, Pennsylvania, USA

**Biography:** Dr. Lech Muszynski is an Assistant Professor in the Department of Wood Science & Engineering at Oregon State University, Corvallis, Oregon. His responsibilities include research and teaching in the area of wood-based composites. Previously, he was an Assistant Scientist and Post-Doctoral Research Associate, Advanced Engineered Wood Composites Center, University of Maine; and Assistant Professor and Graduate Teaching & Research Assistant, Agricultural University of Poznan. He received an M.S. and Ph.D. from the Agricultural University of Poznan.

**Abstract:** In this paper, we will discuss the opportunities, challenges, and limitations related with the application of ultrasonic atomization techniques for adhesive atomization in wood- and other bio-based composites industries. Ultrasonic atomization is a promising alternative to liquid (e.g. resins, wax emulsions, surfactants) atomization techniques currently used in the wood-based particulate panel industry (e.g. MDF, PB, OSB). As opposed to the spinning disk atomization, the ultrasonic atomization produces low velocity ("soft") spray output that can be easily shaped and carried to the target with directed air current generating minimum waste. Another advantage is much better control over the droplet size distribution, which may be engineered very precisely to match specific desired droplet sizes for optimal product properties (like durability, dimensional stability). The ultrasonic atomizers can effectively atomize liquids of high viscosities (up to 300

cps) and suspensions of high solid contents (up to 40% by weight). The theoretical output of a single unit may reach up to 800 ml/min for some liquids. Our recent research confirmed that ultrasonic devices can be used to atomize relatively high viscosity resins, however the maximum flow rates reached in the study with an off shelf ultrasonic nozzles were well below the level of practical interest for the forest products industry (Zhang et al. 2009). The flow rates in the ultrasonic atomization depend on the geometry and output characteristics of the nozzle as well as on the physical properties of the liquid (density, viscosity, surface tension, solid content, and the size of the solid particles). Theoretically, it is possible to significantly increase the flow rates by manipulating these parameters, though the ability to predict the actual flow rate from available theoretical equations and correlations is fairly limited. In practice, the extent to which the physical properties of the liquid may be manipulated is limited by the requirements dictated by the application (in case of the resin, the ability to create a successful bond). Another important concern is that many of these variables do also affect the median (volumetric) droplet size, which is another characteristic that may be determined by the application. Successful commercial application of the ultrasonic devices in forest products industries may require designing special ultrasonic nozzles and special resin formulations.

### Thermal Behavior of Polyurethane Adhesives Bonded to Wood

Klaus Richter, Head, and *Francisco Lopéz-Suevos*, Research Scientist, Wood Laboratory, Empa – Swiss Federal Laboratories of Materials Testing & Research, Dübendorf/Zürich, Switzerland

**Biography:** Dr. Klaus Richter is a Wood Scientist and Head of the Wood Laboratory, Swiss Federal Laboratories of Material Testing & Research (Empa), Dübendorf/Zürich, Switzerland. He graduated from the University of Hamburg in 1983. During his Ph.D. program, he spent 2 years at the Iberian Peninsula where he collaborated, among others, with the 'Instituto de Maderas del INIA' in Madrid. After defending his Ph.D. thesis at the University of Hamburg, he joined the Wood Lab of Empa in 1987 as a Research Scientist. He is involved in research and development and testing activities and knowledge transfer in the fields of wood technology and wood products application in building and construction, wood adhesion, surface treatment, timber modification, wood-polymer interaction, life-cycle assessment of building materials, and sustainability in building and construction. He was elected as Head of the Lab in 2003 and holds teaching assignments at the Technical Universities of Zürich (ETH Zürich) and Graz (TU Graz).

**Abstract:** Thermal stability of structural timber adhesives bonds is becoming increasingly important. Adhesives based on polyaddition reaction (e.g. PUR adhesives) exhibit low glass transition (Tg) temperatures. They undergo changes in the polymeric network when the temperature of the bondline is heated above 80°C and, if under load, thermal creep of the joints results. As one-component PUR adhesives are increasingly used for bonding structural timber elements (surface gluing and finger-jointing) due to a wide range of advantageous properties (short pressing time, low pressure, bonding at higher wood moisture content, no formaldehyde emissions, no shrinkage at curing, transparent bondline) there is urgent need to improve their thermal stability. In the presented research we use: 1) DMTA methodologies to evaluate the viscoelastic response of PUR neat films and PUR-wood composites in an attempt to understand how wood influences the PUR Tg; and 2) modified heat resistance creep tests (EN 14292) to compare the performance of the selected adhesives in the bonded assemblies in the temperature range from 20° to 130°C. Correlations or trends between the creep resistance performance and the PUR Tg will be sought. Effects of chemical modifications of the PUR prepolymers and adhesive formulation on the thermal stability of PUR films and composites are discussed.

### Temperature Dependent Strength of Adhesively Bonded Timber Joints

*Thomas Tannert*, Scientific Collaborator, R&D, Till Vallée, Professor, Structural Engineering, and *Simon Hehl*, Student, Timber Engineering, Bern University of Applied Sciences, Biel, Switzerland

**Biography:** Dr. Till Vallée is a Professor of Structural Engineering including FEA, composite materials, and hybrid structures R&D in the fields of composites and timber, with a focus on fracture and strength prediction methods, including probabilistic methods. Previously, he was Senior Research Scientist/Lecturer and Ph.D. Student, Composite Construction Laboratory, Swiss Federal Institute of Technology; and Freelance Civil Engineer, Vallée Engineering. He received an M.S. from Technische Hochschule Darmstadt, and Ph.D. from the Swiss Federal Institute of Technology.

**Abstract:** It is largely admitted that adhesively bonding better suits the fibrous and brittle nature of timber than mechanical fasteners. Experimental research related to the strength of adhesively bonded timber joints is usually carried out under laboratory conditions. But for practical applications, as in civil engineering, the question of the temperature dependence of adhesively bonded joints, regarding strength and stiffness, always arises and still awaits an answer. Both components of the joint, the wood and the adhesive, exhibit temperature dependant variations of their mechanical properties. A critical issue is the fact that the glass transition temperature of commonly used commercial adhesives (i.e. epoxies or polyurethanes), lies within the range of temperatures that has to be considered for practical applications. The research presented herein reports on the strength of adhesively bonded timber joints subjected to temperatures ranging from –25°C to +75°C (–13°F to 167°F). Besides the experimental report, the authors suggest a strength prediction method that takes into account the temperature and its effects on both the timber and the adhesive.

## Tuesday Morning, September 29

## CONCURRENT SESSIONS

## SESSION 2A: Resin Chemistry 1

### An Overview on Flame-Retardant Structural Wood Adhesives

Jinlan Ju, Research Scientist, and *Xiang-Ming Wang*, Senior Research Scientist and Group Leader, FPInnovations – Forintek Division, Quebec City, Quebec, Canada; *Martin W. Feng*, Senior Research Scientist and Project Leader, FPInnovations – Forintek Division, Vancouver, British Columbia, Canada

**Biography:** Dr. Jinlan Ju is a Polymer Chemist with extensive experience on synthesis, modification, and application of various polymers and nanocomposites. She has an industrial background of chemical engineering as well. Recently, she is working on forest industry, including wood composites and pulp and paper fields. Previously, she was a Research Scientist, FPInnovations – Paprican Division (Pointe-Claire, Quebec); Post-Doctoral Fellow, University of New Brunswick; Assistant Professor, Nanjing University of Technology; Post-Doctoral Fellow, Pohang University of Science & Technology (POSTECH); Chemical Engineer, Nanjing Plastic Plant; and Chemical Engineer, Shanxi Synthetic Rubber Group Co., Ltd. She received a B.Eng. in Chemical Engineering and M.S in Polymer Science & Engineering from Nanjing University of Chemical Technology, and Ph.D. in Polymer Science & Materials from Nanjing University.

**Abstract:** Over the past decade, there has been concern within the wood industry that wood adhesives being used may not perform well when subjected to fire. If the adhesive inside an engineered wood product is soften, decomposed, and burnt at elevated temperatures during a fire, the EWP would collapse even if the integrity of the wood sections are remained relatively intact. Therefore, the fire performance of wood adhesives used in EWP needs to be improved. The fire-safety of a wood adhesive depends on its ability to resist fire and to retain its strength at elevated temperatures. In other words, both of the fire resistance and heat resistance of an adhesive decides whether or not the EWP bonded with this adhesive can sustain sufficient time for people to escape from the building and for firefighters to safely reach the site of the fire. This presentation will overview the common standards and regulations related to fire testing of materials, the mechanism of fire and the methods to improve fire retardancy and heat resistance of various wood adhesives. The critical barriers for designing fire-retardant wood adhesives will be proposed. Especially, the up-to-date commercial fire-retardants from the main manufacturers will be summarized to inspire the developers who work on fire-retardant adhesives.

## Development of Fire-Resistant Polyurethane Structural Wood Adhesives

Jinlan Ju, Research Scientist, and *Xiang-Ming Wang*, Senior Research Scientist and Group Leader, FPInnovations – Forintek Division, Quebec City, Quebec, Canada; *Martin W. Feng*, Senior Research Scientist and Project Leader, FPInnovations – Forintek Division, Vancouver, British Columbia, Canada; *Zhenhua Gao*, Professor, College of Material & Engineering, Northeast Forestry University, Harbin, P.R. China

**Biography:** Dr. Jinlan Ju is a Polymer Chemist with extensive experience on synthesis, modification, and application of various polymers and nanocomposites. She has an industrial background of chemical engineering as well. Recently, she is working on forest industry, including wood composites and pulp and paper fields. Previously, she was a Research Scientist, FPInnovations – Paprican Division (Pointe-Claire, Quebec); Post-Doctoral Fellow, University of New Brunswick; Assistant Professor, Nanjing University of Technology; Post-Doctoral Fellow, Pohang University of Science & Technology (POSTECH); Chemical Engineer, Nanjing Plastic Plant; and Chemical Engineer, Shanxi Synthetic Rubber Group Co., Ltd. She received a B.Eng. in Chemical Engineering and M.S in Polymer Science & Engineering from Nanjing University of Chemical Technology, and Ph.D. in Polymer Science & Materials from Nanjing University.

**Abstract:** Engineered wood products (EWP) have been an important part of many buildings and they would collapse if the adhesive inside an engineered wood product is soften, decomposed, and burnt at elevated temperatures in the presence of fire. Therefore, the fire performance of wood adhesives used in EWP needs to be improved. Among the commonly used structural wood adhesives, phenol-resorcinol-formaldehyde PRF is the most heat-resistant resin due to its 3-dimensional cross-linked molecular structure with aromatic rings of low energy states and highly stabilized methylene-bridges. However, it is a formaldehyde-based adhesive with dark color, which emits toxic formaldehyde during EWP manufacturing and the glue lines are esthetically not appealing. On the contrary, polyurethane (PUR) is formaldehyde-free, fast cure, and give colorless or white glue lines. It is, however, more vulnerable to fire and quickly lose its strength at elevated temperatures. The objective of this research is to enhance the fire performance of moisture-cured polyurethane wood adhesive by improving the crosslink degree, introducing heat-resistant molecular functional groups and flame-retardants to the adhesives via chemical modifications and nano-technology. The heat resistance of the PUR adhesive has been evaluated with the finger joint failure point tested at 220°C under 6.7 MPa tensile loading and the fire retardancy has been measured via LOI and flame spreading rate. The primary experimental results showed that the heat-resistance of PUR adhesives has been dramatically improved, as indicated by the significant increase in the temperature-to-failure from around 100°C to 200°C and in the corresponding time-to-failure from 2 to 22 min.

## Effect of Nano-Clay on the Dynamic Mechanical Properties of Resin Film

*Yucheng Peng*, Graduate Research Assistant, and *Sheldon Q. Shi*, Assistant Professor, Dept. of Forest Products, Mississippi State University, Starkville, Mississippi, USA. Presented by Kaiwen Liang, Post-Doctoral Research Associate, Dept. of Forest Products, Mississippi State University, Starkville, Mississippi, USA

**Biography:** Dr. Kaiwen Liang is a Post-Doctoral Research Associate in the Department of Forest Products, Mississippi State University. Her responsibilities include research on synthesis and characterization of bio-based polyurethane foam reinforced with wood flour and nanoparticles (nanoclays, Polyhedral Oligomeric Silsesquioxanes (POSS) and carbon nanotubes); and investigation of the formula to fabricate natural fiber sheet molding compound. She received a B.S. from GuangDong University of Technology, M.S. from South China University of Technology, and Ph.D. from Mississippi State University.

**Abstract:** The objective of this study was to investigate the effect of nano-clay on the dynamic mechanical properties of resin films. Phenol resorcinol formaldehyde (PRF) resin was used in this study. Two types of nano-clay: Cloisite 10A and Cloisite 30B were used for the PRF modification. Uniform thin cured PRF resin films were carefully prepared. Dynamic mechanical analyzer Q800 was employed to evaluate the tension properties of these resin films over a temperature range of 40ºC to 240ºC. Storage moduli, loss moduli, and tanδ values of these resin films were obtained through the temperature scan testing of dynamic mechanical analysis (DMA). The DMA results showed that storage modulus of cured pure PRF resin film decreased when the temperature increased from 40ºC to 138ºC. At a temperature range of 138ºC to 149ºC, the storage modulus increased as the temperature increased due to the post cross-linking of PRF resin. At a temperature range of 149ºC to 240ºC, the storage modulus remained constant until the degradation happened to the PRF resin films at about 212ºC. Before the degradation temperature, there were two peaks of tanδ values of 0.14 (138ºC) and 0.15 (183ºC). No apparent difference was found on the dynamic mechanical responding trend between the modified PRF and the pure PRF resin films. The DMA testing of modified PRF films indicated that the added nano-clay could slightly reduce the storage modulus and the degree of post cross-linking for PRF resin. It also showed that the tanδ values were increased by adding the nano-clay. Both the two peak values of tanδ of Cloisite 10A (0.16 and 0.17) and Cloisite 30B (0.15 and 0.16) modified PRF films were higher than the corresponding peak values of tanδ of pure PRF resin films (0.14 and 0.15).

## Optimization of the Glass Transition Temperature and Cure Regime for Structural Timber Adhesives used for On Site Bonding

Adlin Sabrina Muhammad Roseley, M.phil./Ph.D. Candidate, and *Martin P. Ansell*, Reader and Head, Sports & Materials Group, Dept. of Mechanical Engineering, University of Bath, Bath, United Kingdom; *Dave Smedley*, Technical Director, Rotafix Ltd., Swansea, United Kingdom

**Biography:** Adlin Sabrina Muhammad Roseley is an M.phil./Ph.D. Candidate in the Department of Mechanical Engineering, University of Bath, Bath, United Kingdom. Her area of study is timber engineering. She received a Diploma in Wood Technology from MARA University of Technology, and Bachelor of Forestry Science and M.S. from University Putra Malaysia.

**Abstract:** On site bonding of structural timbers is usually, but not always, the method adopted for the repair or restoration of heritage buildings by specialist operatives or carpenters and examples of European heritage buildings are cited. This paper examines the formulation, development, and practical on-site use of low exotherm, low elastic modulus, thick film epoxy adhesives which can be used at ambient working temperatures. However, the desirable thixotropic qualities of these adhesives are gained at the expense of low glass transition temperature (Tg). The perception of the European timber restoration industry is that structural timber adhesives should possess a minimum Tg of 50ºC. The thixotropic adhesive systems, which are the subject of this paper, generally possess lower Tg values following room temperature curing. Tg is a function of the formulation and depends on the proportion of nano-fillers and reactive diluents. The paper describes how modifications to the adhesive formulation can increase Tg. Furthermore, the effect of *in situ* post-curing in warmer climates is shown to increase the stability of the adhesive by promotion of secondary cross-linking. The paper explores the microstructure of these thixotropic adhesives and presents data on their mechanical properties measured in static tests and in creep as a function of temperature and relative humidity. The performance of bonded-in connections, based on GFRP rods bonded into LVL, is also evaluated. A Dynamic Mechanical Thermal Analyzer (DMTA) is used to measure Tg and the dynamic mechanical properties of the adhesives. The overall aim is to demonstrate the stability of room temperature cure adhesives at temperatures of up to 50ºC.

## Effect of Curing Procedure on pH and Alkalinity or Acidity of Wood Adhesives

Xiang-Ming Wang, Senior Research Scientist and Group Leader, FPInnovations – Forintek Division, Quebec City, Quebec, Canada; *Romulo Casilla*, Research Consultant, FPInnovations – Forintek Division, Vancouver, British Columbia, Canada; *Yaolin Zhang*, Research Scientist, FPInnovations – Forintek Division, Quebec City, Quebec, Canada

**Biography:** Dr. Xiang-Ming Wang is a Senior Research Scientist and Group Leader of Wood Adhesives at FPInnovations – Forintek Division, Quebec City, Quebec, Canada. He is responsible for R&D in wood adhesives, wood composites, and wood engineered products through conducting national research projects and contracts to support the industrial members' sustainable development goals. Previously, he was Adjunct Professor, Laval University; Post-Doctoral Research Associate, National Renewable Energy Laboratory, U.S. Department of Energy; and Post-Doctoral Research Fellow, Wood Science & Technology Centre, University of New Brunswick. He received a B.S. in Wood Science & Technology from Northeast Forestry University, M.S. in Forest Industries Technology from the University of Wales, and Ph.D. in Wood Science from Laval University.

**Abstract:** Nine formulations were selected for evaluating the effect of different curing procedures on pH and alkalinity or acidity of adhesives. These included four phenol formaldehyde (PF) with high pH, one phenol-resorcinol formaldehyde (PRF) with intermediate pH, two melamine-urea formaldehyde (MUF), and two melamine formaldehyde (MF) with low pH. The four curing procedures used in the study were: 1) curing at 102-105°C for one hour (based on CSA O112.6-1977); 2) four-hour curing at 66°C followed by one-hour curing at 150°C (based on ASTM D1583-00); 3) curing at room temperature overnight (based on ASTM D 1583-00); and 4) cured adhesive squeezed from glue lines of bonded block shear samples. The effect of the different methods on pH of the cured adhesive depended strongly on the individual adhesives. For the PF, the alkalinity was different for the different formulations in the liquid form, while in the cured form, the difference in the alkalinity depended on the curing method used. The MF and the MUF were the adhesives most affected by the method used. In particular, the MUF showed much higher cured film pH values when tested by method 2 compared to the other three methods, while both the cured MF and MUF exhibited quite variable acidity values when measured with the different methods. The PRF showed reasonably uniform cured film pH, but varying acidity values when measured with the different methods.

### Effects of Esters and Resorcinol on Phenolic Resins as Adhesives in MDF Manufacturing

*Martin W. Feng*, Senior Research Scientist and Project Leader, *Guangbo He*, Scientist, and *Axel Andersen*, Senior Technologist, FPInnovations – Forintek Division, Vancouver, British Columbia, Canada

**Biography:** Martin W. Feng is a Senior Research Scientist with wood adhesive expertise well recognized in Canada. He has 24 years experience in research innovation and industrial problem solving. He joined Forintek (now FPInnovations – Forintek Division) in 2000 and has been a Project Leader in the national research programs for wood adhesives, MDF, particleboard, OSB, and value-added wood products. Prior to working at Forintek, he was a Resin Chemist with Borden Chemical. He is a member of the CSA Technical Committee on Wood Based Panels (A369) and has been actively involved with the development of Canadian standards for wood adhesives and wood-based panels. He is also an Adjunct Professor at the University of Toronto and the Fujian Agriculture & Forestry University in China. He has an M.S. in Organic Chemistry from the University of Alberta. He received his Bachelor's degree in Polymer Chemistry from the Sun Yet-Sen University in China.

**Abstract:** PF-bonded composites wood panels exhibit very low formaldehyde emission levels, meeting the most stringent regulations. However, slow cure speed is a major limiting factor for its applications in the economical manufacturing of MDF and particleboard. Commercial PF resins accelerated with esters or resorcinol and their applications in the manufacture of MDF were investigated. It was found that although ethylene carbonate, propylene carbonate and triacetin were very effective in reducing PF resin gel times, these esters caused substantial loss of bonding strength, particularly in the case of PF resins with high alkalinity. The loss of bonding strength increased as the ester loading in the PF resin was increased. On the other hand, resorcinol was not only an effective PF accelerator, but also preserved most of the bonding strength. Resorcinol-accelerated PF adhesive system showed better performance in internal bond strength, bending strength, and water resistance of MDF in comparison with the ester-accelerated PF adhesive systems. The cure speed of the resorcinol-accelerated PF adhesive was evaluated against a UF adhesive in the manufacturing of MDF.

### Radiation and Dual Radiation-Thermal Cure Adhesives for Wood Composites

*David P. Harper*, Assistant Professor, Forest Products Center, University of Tennessee, Knoxville Tennessee, USA

**Biography:** Dr. David P. Harper is an Assistant Professor with a research appointment in the Tennessee Agriculture Experiment Station. He has been an active member of the Forestry, Wildlife & Fisheries faculty since 2004. Dr. Harper received a B.A. in Physics from West Virginia University before transferring to Washington State University in 1996. He then received an M.S. in Civil Engineering in 1998. Dr. Harper went on to receive his Ph.D. in Civil Engineering from Washington State University in 2003. In 2003, he conducted post-doctoral research at the U.S. Forest Service's Forest Products Laboratory in Madison, Wisconsin. Currently, Dr. Harper's work focuses on developing high-value products to serve as revenue streams for an integrated biorefinery and the forest products industry.

**Abstract:** Radiation curable adhesives demonstrate promise as a means of reducing the energy demands of wood composite manufacture. The acrylic, methacrylate, and novel urethane-acrylate thermoplastic adhesive have demonstrated the ability to create a durable wood bond. These adhesives offer a wide range of processing possibilities and material properties. The formulation of novel urethane-acrylate thermoplastic adhesives demonstrate the ability to bond wood in a heating and subsequent radiation cure process. No residual isocyanate was detected after initial cure, but a substantial amount of acrylic functionality was still present. Low amounts of radiation were needed to produce a wood bond of sufficient strength. The adhesives interaction with wood, cure, energy savings, and properties are discussed.

## SESSION 2B: Composites

### The Evolution of Composite Panel Resin Technology

*Bruce M. Broline*, Principal, Broline Consulting, LLC, Pleasant Hill, Oregon, USA; *Tom Holloway*, Technology Manager, Arclin, Springfield, Oregon, USA; *Robert G. Schmidt*, Senior Vice President, Research & Technology, Arclin, Mississauga, Ontario, Canada

**Biography:** Dr. Robert G. Schmidt is Senior Vice President, Research & Technology, Arclin, Mississauga, Ontario, Canada. He is responsible for all new product/process development and longer term research projects for Arclin North America. He received a B.S. in Forestry from the University of Toronto, Ph.D. from Virginia Tech, Master of Business Administration from Queen's University, and Certified Management Accountant Designation from the Society of Management Accountants of Ontario.

**Abstract:** Not so many years ago, prevailing thought was that making an effective amino resin at a mole ratio less than 1.0 was not possible. Things have certainly changed since then. Regulatory pressures have dramatically changed the way we look at what is feasible. Technology forcing legislation like California's new Phase II product emission standards have ushered in a new era of adhesive products and approaches to meeting extraordinary low emission standards. Approaches to meeting Phase II regulations and ULEF standards require a combination of innovative adhesive technology, re-engineered processes, and a better understanding of end uses. The approach to adhesive design and application opportunities will be discussed.

### Soy Containing High Quality CARB II Compliant PB and MDF

*James A. Yavorsky*, Senior Research Scientist, Ashland, Wilmington, Delaware, USA; *Michael J. Birkeland*, R&D Project Manager, HRT-Ashland, Edgerton, Wisconsin, USA; *Richard L. Brady*, Research Scientist, Ashland, Wilmington, Delaware, USA; *James M. Wescott*, CTO and Technical Director-Wood Adhesives, HRT-Ashland, Waunakee, Wisconsin, USA

**Biography:** Dr. James M. Wescott is CTO of HRT and Technical Director of Wood Adhesives for the Ashland/Hercules-HRT program. He leads R&D in bio-based formaldehyde free and low emitting technologies for the commercialization of both CARB II compliant and NAF panels. Previously, he was Technical Director, Eastman Chemical; and Scientist, International Paper. He received a B.S. in Polymer Chemistry from Rochester Institute of Technology, and a Ph.D. in Chemistry from Virginia Tech.

**Abstract:** Natural adhesives have been used for millennia, but the low cost and high reactivity of formaldehyde-based adhesives had relegated them to novelty status. Increasing knowledge of the hazards of formaldehyde along with significant advances in protein adhesive chemistry is bringing soy adhesives into the forefront of wood composite technology. Initially, the soy adhesive systems were relatively high in viscosity at relatively low solids and somewhat lacking in durability. These issues have been addressed and the Soyad® adhesives from H2H Innovations have evolved rapidly into competitive adhesives for CARB II Compliant wood products.

## Producing Panels with Formaldehyde Emission at Wood Levels

*Eleftheria Athanassiadou*, Head, R&D Support Dept., and Intellectual Property Protection Manager, *Sophia Tsiantzi*, R&D Manager, and *Charles Markessinis*, Research Engineer, Chimar Hellas S.A., Thessaloniki, Greece

**Biography:** Eleftheria Athanassiadou is Head of R&D, Support Department, and Intellectual Property Protection Manager at Chimar Hellas S.A., Kalamaria-Thessaloniki, Greece. Her responsibilities include management and administration of research projects and management of protection of Industrial Property Rights.

**Abstract:** The acceptable levels of formaldehyde emission from composite panel products have been continuously reduced over the last decades. The driving forces have been increased public awareness and consumer demand for non-hazardous products as well as corresponding governmental regulations. The latest re-classification of formaldehyde by the International Agency for Research on Cancer as "carcinogenic to humans", has triggered further concern and reactions by worker and consumer associations, "green" organizations, regulatory authorities, and the industry itself. New studies on formaldehyde health effects were initiated since 2005 in both the USA and Europe and corresponding decisions on reclassification have been postponed until the results are available. With the aim to protect people's health and to help the industry satisfy the acceptable formaldehyde levels, CHIMAR has developed novel wood adhesive system technologies, which provide composite panels (particleboards, MDF, thin MDF, plywood, and OSB) conforming to the most stringent formaldehyde standards. Even panel grades with emission at the level of natural wood (Super E0, the Japanese F****) are obtained, while simultaneously maintaining acceptable bonding performance. The proposed adhesive systems are the results of many years' research and experimentation in laboratory, pilot, and industrial environments. In this work, the advantages of such systems are presented. In parallel, the leading standards and regulations concerning formaldehyde emission from wood composites are reviewed and mention is made of the Occupational Exposure Limits worldwide.

## Resins from Soybean Oil-Based Additives for Natural Fiber Sheet Molding Compound (SMC) Composites: Synthesis and Characterization

*Kaiwen Liang*, Post-Doctoral Research Associate, and *Sheldon Q. Shi*, Assistant Professor, Dept. of Forest Products, Mississippi State University, Starkville, Mississippi, USA

**Biography:** Dr. Kaiwen Liang is a Post-Doctoral Research Associate in the Department of Forest Products, Mississippi State University. Her responsibilities include research on synthesis and characterization of bio-based polyurethane foam reinforced with wood flour and nanoparticles (nanoclays, Polyhedral Oligomeric Silsesquioxanes (POSS) and carbon nanotubes); and investigation of the formula to fabricate natural fiber sheet molding compound. She received a B.S. from GuangDong University of Technology, M.S. from South China University of Technology, and Ph.D. from Mississippi State University.

**Abstract:** Unsaturated polyester is the most common resin type used in sheet molding compound (SMC) for automotive applications. Research is ongoing at Mississippi State University to use the natural cellulosic fibers to replace the fiber glass for the SMC composites. Thermosetting resins were synthesized from the soybean oil, which was suited to built not only the crosslink between the functional groups on the unsaturated polyester chains, but also the free radicals to the hydroxyl group research surface of kenaf fibers. Maleinated acrylated epoxidized soybean oil (MAESO) was synthesized by free radical polymerization using the hydroxyl groups on the acrylated epoxidized soybean oil (AESO) reacted with the maleic anhydride (MA). Maleinated acrylated epoxidized soybean oil (MAESO) or acrylated epoxidized soybean oil (AESO) were blended into the unsaturated polyester resin to fabricate the natural fiber reinforced polymer composites. Laminated sheet molding compound (LSMC) process was used to fabricate the composites. Tensile strength, flexural strength, and stiffness were evaluated to obtain an optimum and comparative SMC formulation for natural fiber composites in automotive applications. Fracture morphology was also examined to address interfacial compatibility at the interface between the hydroxyl group rich surface of kenaf fibers and synthesized resin matrix.

## Utilization of Plantation Wood in High Performance Wood-Based Structural Composites

*Andreja Kutnar*, Post-Doctoral Research Associate, and *Fred A. Kamke*, JELD-WEN Professor of Wood-Based Composite Science, Dept. of Wood Science & Engineering, Oregon State University, Corvallis, Oregon, USA; *Milan Sernek*, Associate Professor, Dept. of Wood Science & Technology, University of Ljubljana, Ljubljana, Slovenia

**Biography:** Dr. Andreja Kutnar is a Post-Doctoral Research Associate in the Department of Wood Science & Engineering, Oregon State University, Corvallis, Oregon. She is also currently Manager of Mizarstvo Kutnar Andreja Kutnar s.p. and a Researcher at Primorska Institute for Natural Sciences & Technology, University of Primorska. She received a Ph.D. from University of Ljubljana.

**Abstract:** The aim of this paper is to demonstrate the application of non-structural timber species in novel structural wood-based composites. The laminated composites were manufactured from hybrid poplar (*Populus deltoides* × *Populus trichocarpa*) that was obtained from a plantation in Northwest Oregon. This low-density wood was densified using the viscoelastic thermal compression (VTC) process to three different degrees of densification (63, 98, and 132%). The viscoelastic thermal compressed wood (VTC wood) and undensified wood were used to produce four different 3-layer sandwich composites (0-0-0, 63-0-63, 98-0-98, 132-0-132). The VTC wood laminas were placed in the two outer layers, and undensified wood was placed in the core layer. The composites were tested in four-point bending in order to determine their relevant structural properties. Increased density of the face layers in the 3-layer VTC composites was advantageous for their mechanical performance. Furthermore, the modulus of elasticity (MOE) and modulus of rupture (MOR) of the 3-layer VTC composites were compared with values corresponding to commercially-produced wood composites. The results confirmed that the VTC process enables the use of low-density wood for new high performance structural wood-based composite products.

## Utilization of Chitosan as an Adhesive for Bagasse Particleboard

*Kenji Umemura*, Assistant Professor, *Keiji Kaiho*, Graduate Student, and *Shuichi Kawai*, Professor, Research Inst. for Sustainable Humanosphere, Kyoto University, Kyoto, Japan

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

**Abstract:** To develop high-performance non-wood lignocellulosic board without synthetic resin adhesives, bagasse particleboard bonded with chitosan was investigated. Chitosan was dissolved in 1% acetic acid, and 4wt% chitosan-acetic acid solution was prepared as an adhesive. The solution was sprayed onto the bagasse particles at 2 to 10 wt% chitosan solid content based on the weight of the dried particles. Particleboards with target density of 0.9 g/cm$^3$ were manufactured using a steam-injection press. The steam pressure and total pressing time were 1 MPa (180°C) and 7 min, respectively. As a reference, particleboard bonded with PMDI was manufactured. In bending properties, 2 to 4 wt% addition amount of chitosan was the most effective. The board bonded with a 4 wt% addition showed a good result in the internal bond strength test. In addition, the board with a 4 wt% addition had excellent dimensional stability, equivalent to that of board made using PMDI. The board had also favorable dimensional stability in dilute acetic acid. Based on the characterization of bagasse extract-added chitosan films, it was suggested that chitosan reacted with the extract from bagasse during pressing. The reaction seemed to contribute to the board's good resistance to dilute acid.

### Application of Fundamental Fiber-Adhesive Interactions in the Manufacture of MDF

Warren J. Grigsby and *Armin Thumm*, Scientists, Scion, Rotorua, New Zealand

**Biography:** Dr. Warren J. Grigsby is a Scientist at Scion in Rotorua, New Zealand. His research spans 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. 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 woodfiber products. Through his role, he takes a lead in the direction and coordination of innovative research efforts as well as industry liaison on both commercial and government-funded research. He has been with Scion since 1997 (previously named New Zealand Forest Research Institute) and has a previous background in organic, main group and transition metal-based synthetic chemistry and macromolecular chemistry. Previously, he was a Post-Doctoral Fellow, Monash University; and Post-Doctoral Researcher, University of California, Davis. He received a Ph.D. from the University of Waikato.

**Abstract:** How the adhesive is applied and distributed on fiber has a significant impact of the performance of composite wood panels such as MDF. The manufacture of medium density fiberboard usually involves applying adhesive to the fiber via the blowline prior to the fiber being dried. As a result, this creates contrasting resin distribution and wood fiber cell wall penetration behaviors when comparing adhesive applied to dry fiber in a mechanical blender. We have been investigating the fundamentals of these behaviors and their application to improving the fiber-adhesive interactions and impact on MDF panel performance. Discussed are the relationships of temperature and moisture to determining the extent of this resin movement and penetration into the wood fiber cell wall. Furthermore, these fundamentals have been applied to screen various urea-formaldehyde adhesives whose formulations show a range of fiber penetration behavior. Ultimately, the goal of this work is to develop adhesive chemistry which will potentially lead to optimized UF adhesive formulations and improved panel performance.

## Tuesday Afternoon, September 29

## CONCURRENT SESSIONS

## SESSION 3A: Resin Chemistry 2

### Development of Liquefied Bark Phenolic Resin for Composite Wood Product Applications

Martin W. Feng, Senior Research Scientist and Project Leader, FPInnovations – Forintek Division, Vancouver, British Columbia, Canada; *Gilles Brunette*, Manager, and *Xiang-Ming Wang*, Senior Research Scientist and Group Leader, and *Yaolin Zhang*, Research Scientist, FPInnovations – Forintek Division, Quebec City, Quebec, Canada; *Shixue Ren*, Associate Professor, Northeast Forestry University, Harbin, P.R. China; *Hui Wan*, Research Scientist, FPInnovations – Forintek Division, Quebec City, Quebec, Canada

**Biography:** Martin W. Feng is a Senior Research Scientist with wood adhesive expertise well recognized in Canada. He has 24 years experience in research innovation and industrial problem solving. He joined Forintek (now FPInnovations – Forintek Division) in 2000 and has been a Project Leader in the national research programs for wood adhesives, MDF, particleboard, OSB, and value-added wood products. Prior to working at Forintek, he was a Resin Chemist with Borden Chemical. He is a member of the CSA Technical Committee on Wood Based Panels (A369) and has been actively involved with the development of Canadian standards for wood adhesives and wood-based panels. He is also an Adjunct Professor at the University of Toronto and the Fujian Agriculture & Forestry University in China. He has an M.S. in Organic Chemistry from the University of Alberta. He received his Bachelor's degree in Polymer Chemistry from the Sun Yet-Sen University in China.

**Abstract:** Different barks from different wood species were chosen for this study, in which there are beetle infected pine bark, maple bark, and decayed bark. The barks firstly were liquefied in the phenol at evaluated temperatures for a certain period of time. After that, the liquefied bark was used to develop bark phenolic adhesives. Several bark-based phenolic resins were synthesized with similar synthesis conditions (molar ratio of formaldehyde to phenol, ratio of sodium hydroxide to phenol, solid content, and temperature). The final target viscosity was in range of 200 cps and 300 cps. The curing performance of the synthesized adhesives were evaluated with DSC with different heating rates (2.5°C/min, 5°C/min, 10°C/min, and 15°C/min). The bond quality of bark-based resins was evaluated by lap-shear test. Particleboard (PB) and plywood panels were also manufactured with different processing conditions; and the performance of the resulted panels were tested for static bending (PB) property and lap shear strength (plywood).

### Improved CARB II Compliant Soy Adhesives for Laminates

*James M. Wescott*, CTO and Technical Director-Wood Adhesives, HRT-Ashland, Waunakee, Wisconsin, USA; Anthony (Tony) J. Allen, Senior Research Scientist, Ashland-Hercules Water Technologies, Madison, Wisconsin, USA; *Bryan Spraul*, Scientist, Ashland, Wilmington, Delaware, USA

**Biography:** Dr. Anthony (Tony) J. Allen is a Senior Research Scientist at Ashland-Hercules Water Technologies, Madison, Wisconsin. He is the lead investigator for soy adhesives used in hardwood plywood and engineered wood flooring. He received a B.S. Chemistry and Ph.D. in Polymer Science from the University of Akron.

**Abstract:** Soy-based adhesives that contain a polyamidoamine-epichlorohydrin resin (PAE resin) crosslinker have now been used commercially in the production of decorative hardwood plywood for several years. Problems encountered early on in the development of these adhesives were stability, viscosity, and color issues. More recently many improvements have been developed for soy/PAE resin adhesive technology. These include lower viscosity formulations, a reduction in color formation (darkening), improvements in the ease of handling and improvements in the overall performance and reliability of the system. Advances in cross-linking chemistry along with soy modification have led to these improvements. Soy-PAE resin adhesives are now being used commercially in engineered wood flooring (EWF) and in other lamination applications.

### Investigation on the Structure-Property Relationships of One Component Polyurethane Prepolymers and Formulated Adhesives

Sebastian Clauss, Scientific Assistant and Ph.D. Student, ETH Zürich, Inst. for Building Materials, Zürich, Switzerland; *Joseph Gabriel*, Technical Director, Purbond AG, Sempach Station, Switzerland; *Alexander Karbach*, Head of Solid State & Polymer Analysis, CURRENTA GmbH & Co. OHG, Krefeld, Germany; *Mathias Matner*, Head of R&D Prepolymers, Bayer MaterialScience AG, Leverkusen, Germany; *Peter Niemz*, Professor and Head of Wood Physics Group, Inst. for Building Materials, ETH Zürich, Switzerland

**Biography:** Sebastian Clauss is a Scientific Assistant and Ph.D. Student in the Wood Physics Group at ETH Zürich, Institute for Building Materials, Zürich, Switzerland. From 2000 to 2006, he studied process engineering at the Technical University of Dresden within the field of study wood and fiber technology. Since August 2007, he has been working on his Ph.D. at ETH Zürich, Wood Physics Group. His current project includes structure-property relationships of one-component moisture-curing liquid polyurethane adhesive systems for engineered wood. The group is working in close collaboration with the industrial partners Purbond and Bayer MaterialScience – several papers about this research have been published.

**Abstract:** Due to the wide variation possibilities in the chemical structure of one component moisture curing polyurethane adhesives (1C PUR), application-oriented adhesives can be created for different environmental conditions. The knowledge of relationships between the chemical structure and the resulting bonding properties is limited especially under high temperature conditions. In close collaboration with adhesive and raw material producers, we systematically varied the chemical structure of 1C PUR prepolymers and additionally formulated adhesives out of it. Subsequently, the shear strengths of bondings of these prepolymers and formulated adhesives with beech wood (*Fagus silvatica* L.) were determined in standardized macroscopic shear tests performed at different temperatures. To distinguish between wood and adhesive effects, we extended the investigation to the microscopic scale by means of combined AFM (Atomic Force Microscopy) and nanoindentation measurements. We showed that changes in the adhesives' chemical structure have different effects at the micro- and macroscopic scale. Particularly in high temperature regions, the bonding

performance is positively influenced by the structural improvements. Furthermore, we revealed important information about the wood-adhesive interphase region. The cell wall properties have not been influenced by the adhesives; they showed distinct differences in stiffness and hardness compared to them.

### Morphological Properties of Moisture-Cure Polyurethane Wood Adhesives

Dakai Ren, Graduate Research Assistant and Ph.D. Student, Macromolecules & Interfaces Inst., and *Charles E. Frazier*, Thomas M. Brooks Professor, Dept. of Wood Science & Forest Products, and Director, Wood-Based Composites Center, Virginia Tech, Blacksburg, Virginia, USA

**Biography:** Dakai Ren is a doctoral student in the macromolecular science and engineering graduate degree program at Virginia Tech. He received a B.S. from Beijing Forestry University, and M.S. from Oregon State University.

**Abstract:** The structure-morphology-property relationships of polyurethanes (PURs) have been investigated by many researchers. However, the effects of wood, on the *in situ* morphological features of the moisture-cure PURs have never been studied. The purpose of this research is to determine if (and perhaps how) the phase morphology of PURs is affected by wood. For this purpose, a model PUR system with well-defined hard and soft segments has been developed. Model PUR prepolymers were prepared by the reaction of poly (tetramethylene oxide) glycol (PTMO) with symmetrical 1, 4-phenylene diisocyanate (para-PUR) or with asymmetric 1, 3-phenylene diisocyanate (meta-PUR). The curing process and simultaneous morphology evolution of the PURs were followed by transmission Fourier transform infrared spectroscopy (FTIR). Thermal and mechanical properties of PUR films and PUR/wood composites were evaluated by differential scanning calorimetry (DSC), thermogravimetric analysis (TGA), and dynamic mechanical analysis (DMA). Finally, the morphological features of PUR films and bonded specimens were imaged by tapping mode atomic force microscopy (AFM). Preliminary results from both DMA and AFM tests indicate noticeable morphological differences between the PUR films and PUR inside the PUR/wood composites. Further investigation is needed to confirm the effects of wood on the morphological properties of PURs.

### Performance of 1K Polyurethane in Comparison to Other Wood Adhesives

Ulrich Mueller, Area Manager, Wood Materials Technology, Wood Kplus – Competence Centre for Wood Composites & Wood Chemistry, Linz, Austria and Dept. of Material Sciences & Process Engineering, BOKU – University of Natural Resources & Applied Life Sciences, Vienna, Austria; *Stefan Veigel*, Ph.D. Student, and *Jürgen Follrich*, Research Fellow, Wood Kplus – Competence Centre for Wood Composites and Wood Chemistry, Linz, Austria; *Joseph Gabriel*, Technical Director, Purbond AG, Sempach Station, Switzerland; *Wolfgang Gindl*, Associate Professor, Dept. of Material Sciences & Process Engineering, BOKU – University of Natural Resources & Applied Life Sciences, Vienna, Austria

**Biography:** Dr. Ulrich Mueller is the Area Manager and key researcher of the Competence Centre of Wood Composites & Wood Chemistry (Wood Kplus – Kompetenzzentrum Holz GmbH, Austria). The area management (Wood Materials Technology) includes the scientific and financial control of ca. 20 projects and personal management of approximately 15-18 employees. The area works in strong cooperation with the Austrian and European wood industry. The total annual budget of the area is 1.2 million Euro. Previously, he was Assistant Professor, University of Natural Resources & Applied Life Sciences, Technical employee, Office furniture production company Svoboda; and Researcher, University of Natural Resources & Applied Life Sciences. He received a Diploma (Dipl.-Ing.), Ph.D. in Wood Science & Technology, and Habilitation in Wood Technology degree from the University of Natural Resources & Applied Life Sciences.

**Abstract:** Testing of adhesive bond strength by means of the lap joint test (European Standards EN 302) delivers no clear effect of the different adhesives because of the high percentage of wood failure. However, different adhesives show considerable differences in their stiffness and mechanical properties. Using optical methods (i.e. speckle interferometry), different strain properties of the adhesives can be observed *in situ*. Resorcinol, melamine, and urea-formaldehyde resins as well as polyester and epoxy resins are characterized by increased stiffness and brittleness, whereas 1K-polyurethane adhesives prove low stiffness values and increased ductility. Even though polyurethane adhesives show lower percentage of wood failure they can reach higher ultimate strength than brittle adhesives. For different load cases highly deformable adhesives as polyurethane resins reach higher fractural strength. This can be explained by the ductility of the bond line which lowers peak stresses at the adhesive – wood interface. For brittle adhesives the deformation is shifted into the wood structure causing a high wood fracture percentage at the wood – adhesive interface. Due to the ductile behavior of polyurethane much higher fracture energy was found for polyurethane adhesives. Microscopic investigations and measurements in the vicinity of a bond line by means of nanoindentation showed a wide range of the micro-mechanical properties. Alteration of the micro-mechanical properties of the wood cell wall is caused by the penetration of the resin into the cell lumen and into the cell wall, respectively. Due to the high molecular weight no intra cell wall penetration can be observed for polyurethane resin.

### A Standard Protocol for Testing Adhesive Bond Strength Development Dynamics with the ABES Technique

Philip E. Humphrey, Chief Science Officer, Adhesive Evaluation Systems, Inc., Corvallis, Oregon, USA

**Biography:** Dr. Philip E. Humphrey is Chief Science Officer at Adhesive Evaluation Systems, Inc. in Corvallis, Oregon. His responsibilities include conducting research and development in the fields of adhesion, thermodynamics and micro-mechanics of engineering composite materials; conceptualize and develop instrumentation to serve the bio-medical, aerospace, oil exploration, and building structures sectors; and coordinate socially relevant activities in developing countries. Previously, he was a Faculty member, Oregon State University; Faculty member, Cambridge University; and Materials Scientist, British Petroleum. He received a Ph.D. from the University of Wales.

**Abstract:** The ABES (Automated Bonding Evaluation System) technique and associated instrument has, over the last 5 years or so, become widely used around the world as a means of assessing the bonding characteristics of industrial adhesives and composite binders – particularly the effect of temperature on their speed of strength development. Comparing data collected by diverse users of the ABES technique has, however, so far proven difficult because of the absence of an integrated standard material preparation, bond forming and bond testing protocol. Reported here is a proposed ABES standard so that results may be comparable with tests conducted by other workers who will employ the same protocol. The protocol is summarized and the main aspects discussed and justified. Isothermal strength development plots up to full bond cure for a range of test combinations are presented graphically and described numerically. The recent development of precise and reproducible electronic means of applying adhesive to test bond surfaces enables spread-rate effects (ranging from 2g $m^{-2}$ up to complete films) to be included. An optional pressing head which affects moisture sealing and allows for vapor injection during bond formation is also presented; this controls the tendency for moisture to be lost from test bonds during their heated formation. Further, use of the ABES instrument to evaluate the kinetics of thermal damage of cured adhesive bonds as a function of temperature (up to 265ºC, 509ºF) is also presented. This provides a highly controlled and specific alternative to the present ASTM Standards (e.g. D905 and 4502-92) in which imprecise and sluggish heat transfer and irregular stress distribution muddy the waters. The presented ABES strength development results may be regarded as a data set to provide a context upon which others' tests may be gauged. The results are also used to consider practical mill-level approaches to optimizing adhesion in wood-based composites.

### High Temperature Performance of Structural Soy Adhesives

Christopher G. Hunt, Research Chemist, *Charles R. Frihart*, Head of Wood Adhesives Science & Technology, *Jane O'Dell*, Physical Science Technician, and *Linda Lorenz*, Chemist, Performance Enhanced Biopolymers, USDA Forest Products Laboratory, Madison, Wisconsin, USA

**Biography:** Dr. Christopher G. Hunt is a Research Chemist in the Performance Enhanced Biopolymers Unit at the USDA Forest Products Laboratory, Madison, Wisconsin. His responsibilities include research on soy adhesives for wood-panel products in cooperation with Ashland-HRT; durability of adhesives and coatings on wood; and wood nanostructure and decay mechanisms. He received a Ph.D. in Analytical Chemistry from the University of Wisconsin-Madison.

**Abstract:** We investigated the potential of soy as raw material for adhesive formulations expected to perform at high temperatures, such as in load bearing bonded wood assemblies that must support the structure during a fire. Soy is attractive as a partial or full replacement

of phenol, melamine, or resorcinol formaldehyde adhesives because it can provide good heat and moisture durability in bonded wood structures with a low cost, renewable, domestic, and non-petroleum raw material. We tested high temperature adhesive performance with ASTM 7247 (hot and cold shear block), creep, thermogravimetric analysis (TGA), differential scanning calorimetry (DSC), and the Automatic Bond Evaluation System (ABES) tensile shear specimens. We found that wood failure increased with heat exposure, indicating that soy-based adhesives generally degrade more slowly than the wood substrate.

### Nanomechanical Characterization of Wood Adhesives and Wood Cell Structure

*Jeffrey P. Schirer*, Senior Applications Engineer, Hysitron, Inc., Minneapolis, Minnesota, USA

Quasistatic nanoindentation has become a reliable method to quantitatively and accurately characterize mechanical properties in small-scale structures. Previously unattainable structure-property relationships in heterogeneous materials have been revealed by the site-specific precision of nanomechanical testing, including nanoindentation and nanoscratch. This study investigates nanomechanical characterization of wood adhesives and wood cell structure by way of nanoindentation, dynamic nanoindentation for high spatial resolution modulus mapping, and nanoscratch for friction, tribological characterization, and wood coating/adhesive adhesion studies.

## SESSION 3B: Modeling

### Modeling the Bond Strength Development in Particleboard and MDF

*Christian Lanvermann*, Research Assistant, and *Heiko Thoemen*, Scientist and Lecturer, Dept. of Wood Science, University of Hamburg, Hamburg, Germany

**Biography:** Christian Lanvermann is a Research Assistant in the Department of Wood Science, University of Hamburg, Hamburg, Germany. His responsibilities include work in the wood-based composites group (manufacture, testing). He will begin his doctoral studies in October in Zürich, Switzerland. He received an M.S. in Wood Science & Technology from the University of Hamburg.

**Abstract:** A model that describes the internal bond strength development of particle and fiber mats during the hot pressing process is presented in this paper. The empirical strength model has been integrated in a global three-dimensional model to simulate the relevant mechanisms including the heat and mass transfer and the rheological behavior of the mat during hot pressing. The empirical strength model is based on data generated with the integrated pressing and testing system (ipates). From this data, a mathematical formulation of the model is derived to compute the rate of IB development for a given mat configuration like adhesive type and content as a function of mat density and temperature. This empirical strength model was integrated into the global model to allow a successive calculation of the internal bond strength in both the space and time domain. The data generation as well as the model development and typical simulation results are presented in this paper. The comparison of the model predictions with experimental results shows that the model is capable to predict the cross-sectional strength distribution in a sufficient manner. Furthermore, typical parameters like pressing time and panel density to affect the strength development are reflected in the simulation results. The work presented in this paper provides a step towards the prediction of the mechanical properties of wood-based composites.

### Mechanistic Modeling of Bonding Characteristics and Properties of Wood Composites

*Chunping Dai*, Senior Scientist and Group Leader, *Guangbo He*, Scientist, *Changming Yu*, Visiting Professor, and *Jiankang Chen*, Visiting Professor, FPInnovations – Forintek Division, Vancouver, British Columbia, Canada

**Biography:** Dr. Chunping Dai is a Senior Scientist and Group Leader at FPInnovations – Forintek Division. He is responsible for setting the research priorities and directing the research program for the composites group in FPInnovations' Vancouver laboratory. He is also a project leader for veneer and strand-based composite products. Previously, he was a Research Scientist, Forintek Canada Corporation; and Research Scientist and Adjunct Professor, Wood Science & Technology Centre, University of New Brunswick. He received a B.S. in Wood Processing and M.S. in Forest Engineering from Nanjing Forestry University, and Ph.D. in Wood Science from the University of British Columbia.

**Abstract:** Traditional approaches to studying bonding properties of wood composites have been predominantly trial and error. This presentation reports our recent progress in developing mechanistic models for predicting resin distribution, mat consolidation, and bonding strength properties. The internal bond (IB) strength of a strand wood composite is computed by a series of modular models of resin coverage, strand-to-strand contact, and perpendicular-to-grain strength property of pressed wood. These models are in turn linked to resin spot size, resin content, strand thickness, wood density and panel density. Mechanisms of localized wood damage and bond failure are also considered. The predictions are validated with experimental results. Based on first principles, these models help improve the fundamental understanding of material properties and manufacturing processes of wood composites.

### Wood-Adhesive Bonding Failure: Modeling and Simulation

*Zhiyong Cai*, Project Leader, Engineered Composite Science, USDA Forest Products Laboratory, Madison, Wisconsin, USA

**Biography:** Dr. Zhiyong Cai is Project Leader of Engineered Composite Science at the USDA Forest Products Laboratory in Madison, Wisconsin. His responsibilities include: develop and supervise a broad basic research program that encompasses defining properties, surface modification, and protection of bio-based composite materials; and keep abreast of current literature and ensure that the latest scientific advances in wood- and bio-based composite technology, especially nanocomposites, are incorporated into the Unit's research and that the research is in concert with the U.S. Forest Service and National objectives and industry needs. His research interests include new product development, process evaluation and improvement, and forest sustainability. He received a Ph.D. in Wood Science & Engineering from Purdue University.

**Abstract:** Failure of wood bonding due to exposure to wet conditions or wet/dry cycles is a longstanding problem associated with development of acceptable wood adhesives in the plywood industries. The mechanism of the bonding failure is still not fully understood and the internal stresses exerted upon the wood-adhesive bondline are not quantitatively determined. Unlike previous modeling this study has developed a new two-dimensional internal stress model based on mechanics of layered composites. Plywood panel is regarded as a multi-layered composite material which each layer (including bonding line) has different properties. When the plywood panel experiences moisture changes through its thickness, internal stresses and their corresponding strains will develop among its layers. The model can be used to quantitatively simulate the relationship between the internal stresses and the panel parameters which include layer thickness, modulus of elasticity, linear expansion coefficient, Poisson's ratio, shear modulus, density, and orientation of layers. The results would provide a better understanding of bonding failure during the water exposure test.

### Predicting the Strength of Adhesively Bonded Timber Joints Using a Probabilistic Method

*Till Vallée*, Professor, Structural Engineering, *Thomas Tannert*, Scientific Collaborator, R&D, and *Martin Lehmann*, Assistant, Materials & Wood Technology, Bern University of Applied Sciences, Biel, Switzerland

**Biography:** Dr. Till Vallée is a Professor of Structural Engineering including FEA, composite materials, and hybrid structures R&D in the fields of composites and timber, with a focus on fracture and strength prediction methods, including probabilistic methods. Previously, he was Senior Research Scientist/Lecturer and Ph.D. Student, Composite Construction Laboratory, Swiss Federal Institute of Technology; and Freelance Civil Engineer, Vallée Engineering. He received an M.S. from Technische Hochschule Darmstadt, and Ph.D. from the Swiss Federal Institute of Technology.

**Abstract:** Joining timber structural members using mechanical fasteners does not correspond to the fibrous nature of the material. Adhesive bonding is better adapted, since it permits a smoother load transfer. The strength prediction of adhesively bonded timber joints is difficult due to the anisotropic and brittle nature of the adherend, the complex stress distribution as well as the uncertainties regarding the associated material resistance. As a contribution to help close this knowledge gap, the authors have carried out experimental and numerical investigations on adhesively bonded double lap joints composed of timber and epoxy adhesives. This paper describes the results and suggests a probabilistic method for the strength prediction of adhesively bonded timber joints. The method considers the scale sensitivity of material strength using a Weibull statistical function, and takes into account the

statistical variation in the strength of the material, the magnitude of the stress distributions, as well as the volume over which they act. The probabilistic method presents a mechanical explanation for the increased resistance of local zones subjected to high strain or stress peaks and allows predicting the strength of adhesively bonded timber joints.

### Numerical Modeling and Experiments on the Role of Strand-to-Strand Interface Quality on the Properties of Oriented Strandboard

*John A. Nairn*, Professor and Richardson Chair, and *Edward Le*, Ph.D. Student, Dept. of Wood Science & Engineering, Oregon State University, Corvallis, Oregon, USA

**Biography:** Dr. John A. Nairn is a Professor and Richardson Chair in the Department of Wood Science & Engineering, Oregon State University, Corvallis, Oregon. His research interests include deformation and fracture of wood and wood-based composites; analytical and numerical modeling for all types of materials; fracture mechanics analysis of wood and composites including matrix cracking, delamination, interfacial failure, and fiber failure; nanocomposites; effect of residual thermal stresses in wood and composites; analysis of single-fiber model composites and composite interfaces; durability of composites including physical aging, hygrothermal aging, and fatigue; cracking of coatings and paint systems. Previously, he was a Professor, University of Utah; and Scientist, E.I. duPont deNemours & Co. He received a B.A. in Chemistry from Dartmouth College, and Ph.D. in Chemistry from the University of California, Berkeley.

**Abstract:** An important property of adhesive bonds in wood structures is their ability to transfer stress between components. This property can be expected to play an important role in the stiffness of engineered wood products such as oriented strandboard. Nearly all interfacial tests focus on interfacial failure; these tests measure strength of the interface, but provide no information about how the interface transfers stress prior to failure. As a consequence, little is known about stress transfer mechanics in wood products. This talk will discuss numerical modeling and experimental results on stress transfer in wood composites. The numerical model treats adhesive bonds using the concept of an imperfect interface. The displacement discontinuity at an imperfect interface is proportional to the tractions at the interface. A stiff interface will result in little discontinuity and maximum translation of wood component mechanical properties into bulk properties. If the interface allows slippage, however, the mechanical properties will suffer. The numerical modeling can calculation the mechanical properties of oriented strandboard as a function of realistic strand undulation geometries and of the properties of the glue lines. To provide input to the numerical modeling, a new experimental method was developed to measure strand-to-strand interfacial properties as a function of the amount of glue. The modeling and experiments were done on unmodified strands and on densified strands. The densified strands had superior interfaces. The improvement was attributed to changes in the amount of glue penetration into the strands.

### Discrete Element Modeling (DEM) of the Rotary Drum Blending Process: Input Parameters and Verification

*Gregory D. Smith*, Associate Professor, Dept. of Wood Science, University of British Columbia, Vancouver, British Columbia, Canada; *Graeme Dick*, Technical Coordinator, Weyerhaeuser, Edson Structurwood, Edson, Alberta, Canada

**Biography:** Dr. Gregory D. Smith is an Associate Professor in the Department of Wood Science at the University of British Columbia. His primary area of research interest is the processing-structure-property relationships for the major technology platforms used to manufacture reconstituted wood composites. To this end, his research falls into two areas: 1) Investigation of the resin deposition process during blending for the manufacture of oriented strandboard (OSB) and for particleboard (PB); and 2) Development of mathematical models for motion of strands and resin through a Rotary Drum Blender for making OSB and oriented strand lumber (OSL). He has also been active in the PB area for the manufacture of board suitable for making furniture. This has lead to the investigation on the use of novel, hollow core composite panels also for use in the furniture industry. Previously, he was an Assistant Professor, University of British Columbia; Adhesion Scientist, Forintek Canada Corporation; Adhesion Specialist, MacMillan Bloedel Research; and Teaching Assistant, University of British Columbia. He received a B.A.Sc. and M.A.Sc. from the University of British Columbia, and a Dr. sc. techn. from the Swiss Federal Institute of Technology.

**Abstract:** Resin accounted for approximately 17% of the direct manufacturing costs for oriented strandboard (OSB) in 2006. As OSB producers are increasing their dependency on pMDI-resins, this percentage is likely greater for oriented strand lumber (OSL) and laminated strand lumber (LSL) products. Therefore, there is strong economic incentive to optimize the blending process and minimize the resin content of these products. This work focused on development and use of a discrete element model (DEM) for simulating strand flow in a rotary drum blender. The DEM software required three material and three interaction properties. Development of the model involved creating a virtual blender and strands and assigning appropriate material and interaction properties to the various components. This was accomplished in two steps, completing baseline bench-top experiments and a literature review to determine appropriate parameters and initial value ranges for these properties, and then fine-tuning these values based on a validation process. With this model, an exploratory study was conducted to determine the effect of flight height, number of flights, blender rotational speed, and blender fill level on bulk strand flow. The results were analyzed from the perspective of end users and blender manufacturers and suggest that the rotational speed and tilt angle should be linked directly to the blender feed rate to ensure an optimal blending environment is maintained.

### Mechanical and Dielectric Response of Thermosetting Wood Adhesives During Cure

*Milan Sernek*, Associate Professor, and *Mirko Kariz*, Graduate Assistant, Dept. of Wood Science & Technology, University of Ljubljana, Ljubljana, Slovenia

**Biography:** Dr. Milan Sernek is an Associate Professor in the Department of Wood Science & Technology, University of Ljubljana, Ljubljana, Slovenia. He teaches courses on the subject of wood-based composites manufacture and wood adhesives. He has been working on several projects related to wood adhesives and adhesion, monitoring adhesive cure and bond strength development, and bonding of modified wood. Previously, he was an Assistant Professor, University of Ljubljana; Graduate Student, Virginia Tech; and Young Researcher, University of Ljubljana. He received a B.S. and M.S. from the University of Ljubljana, and a Ph.D. from Virginia Tech.

**Abstract:** Dielectric analysis (DEA) has been identified as a suitable method for continuous in-process monitoring of the cure of thermosetting adhesives in wood-based composite manufacturing. A durable remote dielectric sensor, mounted on the end of a flat cable, allows it to be inserted directly into the material while consolidated under high temperature and pressure in a hot-press. DEA can give manufacturers the ability to improve the quality and efficiency of the production process, although this technique itself cannot directly reveal the mechanical properties of the adhesive bond. This is the main deficiency of DEA, because for practice, mechanical properties of the adhesive bond line are used to determine the quality of the bonding. Therefore, the objective of this study was to reveal the relationship between mechanical and dielectric response of phenol-formaldehyde (PF) and urea-formaldehyde (UF) wood adhesives during cure. Mechanical response was monitored by oscillatory test using an ARES G2 rheometer with parallel plate geometry, whereas the DEA was carried out using a fringe field sensor (IDEX, Netzch 066S) positioned in the adhesive bond line and connected to an Agilent 4285A LCR Meter. The results showed that the mechanical response of the adhesive was correlated with the dielectric response, but dependable on the adhesive type and formulation. The obtained data was used to derive the empirical models that describe the cure process of the studied adhesives.

### Rheological Characterization of Wood Adhesives and Droplet Size Prediction

*Xuelian Zhang*, Post-Doctoral Research Associate, School of Forest Resources, Penn State University, University Park, Pennsylvania, USA; *Douglas J. Gardner*, Professor and Program Leader of Wood Science, School of Forest Resources and AEWC Advanced Structures & Composites Center, and *Douglas W. Bousfield*, Professor, Dept. of Chemical & Biological Engineering, University of Maine, Orono, Maine, USA

**Biography:** Dr. Douglas J. Gardner is Professor and Program Leader of Wood Science in the School of Forest Resources and the AEWC Advanced Structures and Composites Center at the University of Maine. His 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 cellulose nanocomposites. He has coauthored over 120 technical publications and 100 research presentations. Dr. Gardner is Past President of the Society of Wood Science & Technology. He is also a member of the Adhesion Society, American Chemical Society, and Forest Products Society. 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 the 2004-2005 G. Peirce and Florence Pitts Weber Outstanding Researcher in Forest Resources Award, the 2007 Director's Outstanding Faculty Award at the AEWC Center (University of Maine), and the 2008 Forest Products Society L. J. Markwardt Wood Engineering Award. He appeared in Strathmore's Who's Who 2007-2008. In December 2005, he was a visiting lecturer at Beijing Forestry University, and in June 2006 was a visiting lecturer at BOKU (Vienna, Austria). He was made an Honorary Member of the Union of Wood Processing Manufacturers of the Slovak Republic in 2000. He received a B.S. in Forestry (1980) and Certificate of Advanced Study in Pulp & Paper Management (1981) from the University of Maine, and a Ph.D. from Mississippi State University (1985).

**Abstract:** The uniform spray application of adhesives to wood chips determines the final quality of the product. A controlled stress rheometer (CVO Bolin) and an extensional rheometer (CaBER, Haake) were used to characterize the shear and extensional properties of phenol-formaldehyde (PF) and polymeric diphenylmethane diisocyanate (pMDI) resins. The drop size and distribution of these resins under spinning disk atomization were characterized using in a laser diffraction Analyzer. Both resins exhibited Newtonian behavior under shear rates from 1s-1 to 1000 s-1, and the viscous modulus dominated the viscoelastic property over an oscillatory frequency of 0.1 Hz to 3 Hz. However, PF resin formed a more stable filament under extension and has a longer breakup time than the pMDI resin. The extensional viscosities of both resins were much higher than three times their respective apparent shear viscosity, indicating that both resins are non-Newtonian fluids under extensional flow. The predicted drop size based on previous models is compared to the experimental results.

## Wednesday Morning, September 30

## CONCURRENT SESSIONS

## SESSION 4A: Bio-Based

### Development of Liquefied Lignin Phenolic Resin for Composite Wood Product Applications

*Yaolin Zhang*, Research Scientist, and *Xiang-Ming Wang*, Senior Research Scientist and Group Leader, FPInnovations – Forintek Division, Quebec City, Quebec, Canada; *Martin W. Feng*, Senior Research Scientist and Project Leader, FPInnovations – Forintek Division, Vancouver, British Columbia, Canada; *Shixue Ren*, Associate Professor, Northeast Forestry University, Harbin, P.R. China; *Stephane Nadon*, former Technologist, and *Dian-Qing Yang*, Research Scientist, FPInnovations – Forintek Division, Quebec City, Quebec, Canada

**Biography:** Dr. Yaolin Zhang is a Research Scientist at FPInnovations – Forintek Division in Quebec City, Quebec, Canada. He has more than 10 years' research experience specialized in polymer synthesis, characterization, and evaluation. Six years' research experience on R&D of epoxy resin systems. Extensive experience on R&D of value-added polymers, polymer composites, and wood polymer composites. Experience with experimental design, data analysis through statistic approach, and interpretation of structure and property relationship of polymer materials. He has more than 20 publications in peer-reviewed journals with over 10 presentations conducted at international conferences. Previously, he was a Post-Doctoral Fellow, University of Alberta; NSERC Post-Doctoral Research Fellow, Forintek Canada Corporation and University of New Brunswick; Research Assistant, Laval University; Chemical Engineer and Consultant, China International Chemical Consulting Corporation; and Research Engineer, Institute of Carbon Fiber & Composites (also known as China National Research Center of Carbon Fiber). He received a Bachelor of Engineering in Polymer Materials and M.S. in Polymer Materials from Sichuan University (formerly Chengdu University of Science & Technology), and a Ph.D. in Chemical Engineering (Polymer Materials) from Laval University.

**Abstract:** Different types of lignin from different pulp & paper process were chosen for this study, including commercial ammonium lignosulfonate, magnesium lignosulfonate, commercial Kraft lignin and organosolv lignin. These lignin samples were used for adhesive development as received and modified by liquefaction in the phenol at evaluated temperatures. Several lignin-based phenolic resins were synthesized with similar synthesis conditions (such as molar ratio of formaldehyde to phenol, ratio of sodium hydroxide to phenol, solid content, and temperature). The final target viscosity was controlled between 200 cps to 300 cps for these resins. The curing performance of the synthesized adhesives were evaluated with DSC at different heating rates (2.5 °C/min, 5 °C/min, 10°C/min and 15 °C/min). The bonding performance of these lignin-based resins was evaluated by manufacturing particleboard (PB) and plywood panels with different processing conditions and testing the resulted panels for mechanical properties.

### Soy Adhesive – Moisture Interactions

*Christopher G. Hunt*, Research Chemist, and *Charles R. Frihart*, Head of Wood Adhesives Science & Technology, Performance Enhanced Biopolymers, USDA Forest Products Laboratory, Madison, Wisconsin, USA; *James M. Wescott*, CTO and Technical Director-Wood Adhesives, HRT-Ashland, Waunakee, Wisconsin, USA; *Linda Lorenz*, Chemist, Performance Enhanced Biopolymers, USDA Forest Products Laboratory, Madison, Wisconsin, USA

**Biography:** Dr. Christopher G. Hunt is a Research Chemist in the Performance Enhanced Biopolymers Unit at the USDA Forest Products Laboratory, Madison, Wisconsin. His responsibilities include research on soy adhesives for wood-panel products in cooperation with Ashland-HRT; durability of adhesives and coatings on wood; and wood nanostructure and decay mechanisms. He received a Ph.D. in Analytical Chemistry from the University of Wisconsin-Madison.

**Abstract:** One barrier to the broad use of soybean-based adhesives is their sensitivity to water. We have observed an increase in wet performance in adhesives made with soy concentrate over those with flour, both with polyaminoepichlorohydrin crosslinking agent. In this work, we identified the components of soy flour responsible for reduction in wet performance.

### Soy Latex Like Adhesive for Wood Veneer Applications

*Guangyan Qi*, Graduate Research Assistant and Ph.D. Student, and *Xiuzhi (Susan) Sun*, Professor, Dept. of Grain Science & Industry, Kansas State University, Manhattan, Kansas, USA

**Biography:** Dr. Xiuzhi (Susan) Sun is a Professor of Grain Science & Industry at Kansas State University (KSU), and the Director of the Center for Bio-Based Polymers by Design at KSU. She received her Ph.D. in Agriculture & Biological Engineering (1993) from the University of Illinois at Urbana-Champaign, and did her Post-Doctoral training at Texas A&M University. Her research interests include plant proteins extraction and modification, polypeptides and protein nano structures and adhesion, bio-based latex adhesives, poly(lactic acids) and sugar-based thermoplastics compounding and synthesis, bio-nanocomposites, thermodynamics and rheological properties of bio-based polymers. She is the author and coauthor of 100+ peer reviewed journal articles and 6 patents issued and 3 patents pending. She is the coauthor of a book *Bio-Based Polymers and Composite* published by Elsevier in 2005. She is the Associate Editor of *Journal of Bio-Based Materials & Bioenergy* and *Journal of Cereal Chemistry*. She was an invited speaker for numerous scientific symposia and international conferences. Dr. Sun is a member of the AACC, BEPS, AAAS, ACS, ASBAE, AOCS, and The Scientific Research Society Sigma Xi. She is the recipient of Sigma Xi Outstanding Senior Scientist Award in 2007. She was appointed as the USDA National Research Initiative Technical Panel Manager of Bio-Based Products & Bioenergy for two years (2004 and 2005). She serves on the committee of the USDA multi-states project *Science and Engineering of Biorenewables and Bioeconomy*. She participates in national strategic research planning workshops and program review panels in bio-based materials and bioenergy areas for USDA, DOE, EPA, and NSF.

**Abstract:** Soybean protein has shown great potential for replacing petroleum-based polymers for adhesive application. Soybean protein modified with sodium bisulfite behaves like latex adhesives, with comparable adhesion strength to formaldehyde-based adhesives. The objective of this research was to investigate the compatibility of soy latex adhesive with six commercial wood veneer glues. Different levels of soy latex adhesive including 0%, 20%, 40%, 60%, 80%, and 100% (total weight basis) were blended with wood veneer glues, and adhesion, rheological, thermal, infrared spectroscopy (FTIR), and morphological properties of the mixed adhesive were characterized. Dry adhesion strength of the soy latex were the same as all six wood veneer glues, and the dry adhesion of commercial wood veneer glues also maintained the same after blending with soy latex adhesive at various loading levels. Water resistance of wood veneer glues was improved by blending soy latex adhesive and wet strength was increased with the percentage of soy latex adhesive increasing. For example, wet strength of press bond glue (PBG) increased from 4.66 MPa to 6.416 MPa with 100% wood failure when 40% of soy latex adhesive was added to the PBG. Viscosity of wood veneer glue were reduced significantly, and reached the lowest value at soy latex adhesive loading level from 40% to 60%. Thermal and FTIR studies showed that chemical reactions occurred between soy protein molecules and selected commercial wood veneer glues.

### Comparing Soy Protein Isolate and Wheat Gluten as Bio-Based Binders for the Wood Industry

*Petra Nordqvist*, Ph.D. Student, and *Eva Malmström*, Professor, Dept. of Fibre & Polymer Technology, Royal Inst. of Technology, Stockholm, Sweden; *Farideh Khabbaz*, Senior Research Chemist, Casco Adhesives AB, Stockholm, Sweden

**Biography:** Petra Nordqvist is a Ph.D. Student in the Department of Fibre & Polymer Technology, Royal Institute of Technology, Stockholm, Sweden. She has been an industry-based doctoral student for the last 2 years. She shares her time between the Department of Fibre & Polymer Technology, Royal Institute of Technology, and Casco Adhesives AB. Previously, she was a Senior Research Chemist, R&D Engineer, and Analytical Chemist, Casco Adhesives AB. She received an M.S. in Chemistry from the University of Stockholm.

**Abstract:** There is a growing interest in plant protein-based adhesives for wood due to an increasing environmental concern regarding petroleum-based products. Recent research has mainly been focused on the gluing properties of soy protein and especially how the water resistance can be improved. However, since the soybean plant is not native worldwide, it is of interest to also study proteins from other plants, such as wheat gluten from wheat. In this study, tensile strength of beech substrates glued with dispersions of alkali-modified soy protein isolate (SPI) and wheat gluten (WG) was measured for comparison of bond strength and resistance to cold water. The proteins were denatured with 0.1 M NaOH (pH 13). Dispersions with different protein concentration and viscosity were investigated. Two types of application methods were used to overcome the problem with different viscosities of the dispersions. The particle size of dispersed proteins was measured and the glue joints were studied by light microscopy. The aim of the study was to compare the gluing properties of the two types of protein, and to investigate how the particle size and the degree of penetration of the dispersions into the wood influence the gluing properties. According to the results, there is a clear difference in performance between the two proteins. The gluing properties of SPI are superior, particularly with regard to water resistance. However, the water resistance of WG was partly improved when starved glue joints could be avoided. The study was performed within EcoBuild (Sweden), which is a Centre of Excellence for eco-efficient and innovative wood-based materials.

### Protein Hybrid Adhesives: Adhesive Performance, Formulation Latitude, and Chemical Structure

*Joseph J. Marcinko* and *Anthony A. Parker*, Principal Scientists, Advanced Biopolymer Technologies, Mantua, New Jersey, USA

**Biography:** Dr. Joseph J. Marcinko is a Principal Scientist with Advanced Biopolymer Technologies. He is also Principal Scientist and founder of Polymer Synergies LLC. Dr. Marcinko has over 25 years of industrial R&D, research management, and academic experience. His interest and expertise are in the areas of polyurethane chemistry, biopolymers, adhesion science, composite materials, polymer characterization, solid-state NMR spectroscopy, and polymer structure-property relationships. He is an Adjunct Professor at Cumberland County College where he teaches Physical Science, Environmental Science, and Principles of Science. He also holds a secondary education teaching certification. Dr. Marcinko has authored over 30 publications, and has 4 patents, plus 7 patents pending. He received a Pennsylvania Professional Teaching Certification, B.S. in Chemistry, and B.S. in Biology from King's College; M.S. in Chemistry from Case Western Reserve University; and Ph.D. in Chemistry from the University of Akron.

**Abstract:** Bio-derived adhesives are growing in application for wood composites. The potential cost benefits and renewable resource characteristics are increasingly justifying the development of bio-based polymers not only for composite wood, but also for other industries such as the automotive industry, packaging industry, and the appliance and construction industries. As part of an ongoing effort in our laboratory, our R&D team has undertaken the development of a novel series of bio-protein derived materials for use as adhesives. In these studies, ASTM D-905 physical property data are presented for a series of one and two component adhesives from our portfolio of products and biopolymers. Spectroscopic evidence is also discussed in which the protein chemistry and potential for reaction with other adhesive molecules is shown. Discussion of the formulation latitude and the ability to tailor the performance of these adhesives for structural and non-structural applications will be illustrated.

### Improve the Water Resistance of Soy-Based Adhesive by Using Sodium Dodecyl Sulfate and Glutaraldehyde

*Fei Li*, Research Assistant, and *Xiaoping Li* and *Weihong Wang*, Professors, College of Materials Science & Engineering, Northeast Forestry University, Harbin, P.R. China

**Biography:** Dr. Weihong Wang is a Professor in the College of Materials Science & Engineering, Northeast Forestry University, Harbin, P.R. China. Her responsibilities include research on wood-plastic composite, agriculture-fiber composite, and soy-based adhesive. Previously, she was an Associate Professor and Lecturer, Northeast Forestry University; and Engineer, Forestry Design & Research Institute of Heilongjiang Province. She received a Master and Ph.D. from Northeast Forestry University.

**Abstract:** Soy flour (SF) has been used to prepare adhesive for a long time, but its water resistance is not satisfactory. In the present study, sodium dodecyl sulfate (SDS) and glutaraldehyde (GA) were used to improve the water resistance of SF adhesive. Results showed that the treatment with SDS at pH 5 was beneficial for improving the bonding strength. The reaction temperature had a significant effect on protein denaturation and water resistance. Samples modified at 30°C showed the highest shear strength after water treatment. In addition, pH 12.0 was the optimum condition for GA modification, and the resulting adhesive showed the greatest water resistance for 0.80 wt.% GA (based on the mass of defatted SF). The viscosity increased with the storage time, but the product still had good bonding strength within 6.0 h. The shear strength of the final product was 0.68 MPa after water soaking at 63°C for 3 h. When tested according to ASTM D1183-03, a 14.2% increase in bonding strength was observed after three laboratory aging cycles. It is presumed that crosslinkage be formed based on SDS-PAGE and FT-IR analysis, these may explain why such adhesive was better resistant to water.

## SESSION 4B: Engineered Wood

### Evaluation of Adhesive Bonds in Glulam Posts with Thermally Modified Spruce

*Marielle Henriksson*, Researcher, and *Magdalena Sterley*, Researcher, SP Technical Research Inst. of Sweden, Stockholm, Sweden and Ph.D. Student, Växjö University, Växjö, Sweden; *Jonas Danvind*, Researcher, SP Technical Research Inst. of Sweden, Skellefteå, Sweden; *Mats Westin*, Researcher, SP Technical Research Inst. of Sweden, Borås, Sweden

**Biography:** Magdalena Sterley is a Researcher at the SP Technical Research Institute of Sweden, Stockholm, Sweden. She is currently working on projects dealing with the mechanical properties of glue lines including fracture mechanics and is an expert in gluing technology related to wood products. Her special area of research is green gluing (i.e. gluing of undried wood, which is also the objective of her doctoral studies conducted at Växjö University). She also works with multivariate statistics (PLS partial least square regression) mainly connected with evaluation of NIR-spectra of wood and modified wood as well as transport of water in wood investigated with MRI technique. Previously, she was a Researcher, Trätek Swedish Institute for Wood Technology Research; Research Engineer, Research & Development Institute of Polish Railways; and Research Engineer, Institute of Industrial Chemistry. She received an M.S. from Warsaw University of Life Sciences, and Licentiate of Engineering from KTH Royal Institute of Technology.

**Abstract:** Glulam posts and other type of engineered wood products from thermally modified wood is a research field of increasing activity. Thermally modified wood show a lower moisture content, smaller moisture movements and improved durability compared with untreated wood. Meanwhile the environmental impact of thermally modified wood is lower compared with impregnated wood. In this study, glulam posts with thermally modified wood have been prepared by two different methods, thermal modification of glulam posts and gluing of thermally modified boards. The advantage with thermally modified glulam posts is that the gluing is carried out on unmodified wood. The disadvantage is that the adhesive needs to sustain the high temperature as well as the large shrinkage occurring in the individual boards during the thermal modification process. For the posts prepared by gluing thermally modified wood the challenge is the changed surface properties of thermally modified wood. Four different kinds of commercial

adhesives has been used; EPI, MUF, MF, and PRF. The structure of the adhesive joints was evaluated in optical and scanning electron microscope while the mechanical performance was evaluated by shear strength and delamination tests. The thermal modification of glulam posts was successful since interior cracking was avoided even though the posts were of 90 mm thickness. The emulsion polymer isocyanate adhesive did not withstand the high temperatures during thermally modification process, but the other systems performed well. The adhesive bonds in the posts glued with thermally modified boards showed somewhat lower shear strength, but high wood failure percentage.

### Innovative Programs Led in France to Promote the Use of Domestic Woods in the Field of Engineered Wood Products

Frédéric Simon, Innovation Manager, Research & Innovation Direction, Timber Engineering Unit, FCBA Technological Inst., Bordeaux, France; *Ronny Bredesen*, Research Scientist, Wood & Specialty Adhesives, Dynea AS, Lillestrøm, Norway

**Biography:** Dr. Frédéric Simon is the Innovation Manager, Research & Innovation Direction, Timber Engineering Unit, FCBA Technological Institute (formerly CTBA) in Bordeaux, France. His is also Project Manager for the European Technology Transfer programs dedicated to promoting the use of domestic woods for innovative and sustainable engineered wood-based products; Research Programs Coordinator for all FCBA departments; technical support for Innovation & Development programs on wood-based products within the framework of the French/European regulations for building applications (CE Marking, European Standards, etc.); assessment of wood-based products (plywood, wood-based panels, window frames, glulam beams, EWP, wood polymer composites, adhesives for load bearing timber structures, etc.) for performances characterizations – testing methodology, results evaluation, and interpretation; adhesives' approval expert for load bearing timber structures – technical support onsite for production lines in glulam plants; and expert for onsite timber structures assessment. He received a Master's in Mechanics of Materials & Structures, and a Ph.D. in Wood Mechanics from the University of Bordeaux I.

**Abstract:** The aim of this paper is to present three innovation projects led in France by FCBA during last years and focused on increasing the use of domestic woods in some special applications as Engineered Wood-Based Products made with well suited wood adhesives regarding the final product destination. Furthermore, all these projects were designed to lead to a direct technology transfer for an immediate industrial production. Those different topics can be presented as following: 1) Development of an innovative eco-barrel for wine and alcohol ageing made from laminated composite sleeves (made from one MUF adhesive system bonding two different wood species, ash and oak) giving all the warranties required for alimentary contacts and wine ageing. Such a production process allows to strongly increase the final output of the oak consumption (more than three times) and allows also to decrease the final price of the barrel by 40%. One of the most important properties observed for the glulam barrel is also to reduce of 15% the wine evaporation during ageing in comparison with traditional barrels. 2) Development of a green wood finger jointing industrial chain to improve the use of French spruce for load bearing timber structures made with one PU adhesive system, added to the way of recognition by the building market. 3) Development of some innovative structural glulam beams made from different mechanical low graded wood qualities of Maritime Pine (including packaging quality) and two-component structural EPI adhesive system to reach the Eurocode 5 performances' requirements.

### Ductile Adhesively Bonded Timber Joints

*Maurice Brunner*, Professor, Structural Analysis, Till Vallée, Professor, Structural Engineering, and *Thomas Tannert*, Scientific Collaborator, R&D, Bern University of Applied Sciences, Biel, Switzerland

**Biography:** Dr. Till Vallée is a Professor of Structural Engineering including FEA, composite materials, and hybrid structures R&D in the fields of composites and timber, with a focus on fracture and strength prediction methods, including probabilistic methods. Previously, he was Senior Research Scientist/Lecturer and Ph.D. Student, Composite Construction Laboratory, Swiss Federal Institute of Technology; and Freelance Civil Engineer, Vallée Engineering. He received an M.S. from Technische Hochschule Darmstadt, and Ph.D. from the Swiss Federal Institute of Technology.

**Abstract:** Although it is now admitted that adhesively bonding performs better in terms of strength when it comes to join timber members, this technique suffers from the lack of ductility, as joints usually fail in a very brittle manner. This is due to the fact that the commonly used adhesives exhibit strengths that outperform timber as a material. Even if the considered adhesive exhibits plastic behavior, failure usually occurs at load levels that do not allow for the corresponding plastic behavior to result in significant ductility. To overcome this problematic, the authors have collaborated with an industrial partner to design an adhesive that develops plastic behavior at relatively low strains, while still allowing load transmission at very large strains. To validate the theoretical model, an extensive experimental program was carried out to show that achieving ductile timber joints is possible when using the right adhesive.

### Low Intrusion Techniques for Strengthening of Timber Structures in Reconstruction

Kay-Uwe Schober, Professor of Timber Engineering & Structural Design, Mainz University of Applied Sciences, Mainz, Germany; *Karl Rautenstrauch*, Professor and Head, and *Markus Jahreis*, Research Associate, Dept. of Timber & Masonry Engineering, Bauhaus-University of Weimar, Weimar, Germany

**Biography:** Dr. Kay-Uwe Schober is a Professor of Timber Engineering & Structural Design at Mainz University of Applied Sciences, Mainz, Germany. He is also Owner of Planungsbüro Schober, Architects & Civil Engineers. Previously, he was a University Assistant in Structural Design, Dortmund University of Technology; and Partner, Schober + Partner Architects. He received a Dipl.-Ing. from Dresden University of Technology, and Ph.D. from Bauhaus-University of Weimar.

**Abstract:** Rehabilitation and strengthening of timber structures desires efficient techniques and smart materials with a high load-bearing capacity. To obtain the benefits of these, an efficient connection between the structure and the reinforcing material is necessary. One solution is adhesive mounting to obtain an almost stiff bond line between the different components. Recent investigations indicate Fiber Reinforced Plastics (FRP) and Epoxy Polymer Concrete can be effectively used to improve strength and stiffness of timber beams in different configurations and techniques to utilize the material efficiently and to ensure long service life of the selected system. Here, FRP has been used near surface mounted (NSM) by reinforcing the timber bearing systems for higher tension and shear resistance, similar to concrete structures. This method is relatively simple and considerably enhances the bond of the mounted FRP reinforcements. A high compression proof epoxy concrete was used with NSM to strengthen the compression zone. Both techniques are suitable for on-site application due to an easy use in transportation and mounting. All composite partners have been revised according the material formulation, structural performance of the composites, fracture and delamination behavior. Appropriate mechanical models for the numerical simulation based on a finite element approach have been developed. The main advantage is the highly improved structural performance with only low intervention touches in specific areas, as well as low self-weight of the thin reinforcement layers. This paper presents different aspects for on-site use where first examples in reconstruction and strengthening of timber structures using this system are done. Furthermore, a numerical and theoretical model is presented. The used mechanical model show good agreement with recent test results and addresses structural nonlinearities and FRP debonding. For static analyses, the described adhesive bonding system can set with direct and rigid connection between timber and reinforcement material. The proposed application can be advised in historic buildings even the expense of the materials themselves are quite high. In fact, the expense of the whole procedure often is lower compared to traditional reconstruction systems.

### Flat Wise Green Gluing of Norway Spruce for Structural Application

Magdalena Sterley, Researcher, SP Technical Research Inst. of Sweden, Stockholm, Sweden and Ph.D. Student, Växjö University, Växjö, Sweden; *Erik Serrano*, Professor, and *Bertill Enqvist*, Research Engineer, Växjö University, Växjö, Sweden

**Biography:** Magdalena Sterley is a Researcher at the SP Technical Research Institute of Sweden, Stockholm, Sweden. She is currently working on projects dealing with the mechanical properties of glue lines including fracture mechanics and is an expert in gluing technology related to wood products. Her special area of research is green gluing (i.e. gluing of undried wood, which is also the objective of her doctoral studies conducted at Växjö University). She also works with multivariate statistics (PLS partial least square regression) mainly connected with evaluation of NIR-spectra of wood and modified wood as well as transport of water in wood investigated with MRI technique. Previously, she was a Researcher, Trätek Swedish Institute for Wood Technology Research; Research Engineer, Research & Development

Institute of Polish Railways; and Research Engineer, Institute of Industrial Chemistry. She received an M.S. from Warsaw University of Life Sciences, and Licentiate of Engineering from KTH Royal Institute of Technology.

**Abstract:** Unseasoned (green) Spruce timber planks with dimensions 25 x 150 x 5400 $mm^3$ were flat-wise glued with a one-component PUR adhesive, forming laminated beams with 150 x 300 $mm^2$ cross-section. After curing, each beam was divided in two halves and subsequently dried. The final cross-section of the beams was thus 50 x 300 $mm^2$. The evaluation of the beams included bending stiffness and bending strength in 4-point bending and the mechanical properties of the adhesive bonds. The adhesive bonds were tested according to European standards for glued-laminated timber (EN 392, EN 391) and according to ASTM D 905, but also with a special small-scale specimen for testing the fracture properties of the adhesive bond in Mode I. The complete force vs. deformation curve, including both the ascending and the descending parts could be obtained. The deformations were measured with a contact-free technique, based on two cameras and white light. The equipment made it possible to register the strain in the bond line and in the adjacent wood with a high spatial resolution (0,2 mm). The strength of the bond line and the fracture energy was calculated. Results show that both the stiffness and the strength of the beams can comply with the requirements for glued-laminated timber class L40. The adhesive bonds fulfill the requirements of glulam in standard EN 386. The tensile strength and fracture energy measured with the small specimens of green-glued bond lines is on the same level as of conventionally glued bond lines.

## Wednesday Afternoon, September 30

## CONCURRENT SESSIONS

## SESSION 5A: Analytical

### Small Specimen Wood-Rheology: A Tool to Understand HMR Coupling Mechanism

Sudip Chowdhury, Graduate Research Assistant, and *Charles E. Frazier*, Thomas M. Brooks Professor, Dept. of Wood Science & Forest Products, and Director, Wood-Based Composites Center, Virginia Tech, Blacksburg, Virginia, USA

**Biography:** Sudip Chowdhury is a Graduate Research Assistant in the Department of Wood Science & Forest Products at Virginia Tech, Blacksburg, Virginia. His responsibilities include research as a part of his doctoral studies. Previously, he was a Graduate Research Assistant, Washington State University. He received a B.S. in Chemistry from the University of Calcutta (Kolkata, India), M.S. in Wood Science & Technology from the Forest Research Institute (Dehradun, India), and M.S. in Civil & Environmental Engineering from Washington State University.

**Abstract:** A rheological technique was developed to analyze the structure/property relationship of wood polymers using the smallest possible specimen size. Parallel plate torsion analysis was used with 8 mm diameter discs with a thickness of 6 mm. This small specimen size should be very useful for certain size-constrained sample types, such as those from the stems of genetically modified saplings, or tree increment bores, or within wood-adhesive bondlines, or even from thin surface layers of chemically modified substrates. In dry wood, softening (Tg) of lignin and hemicellulose occur above 180°C. This high temperature causes thermal decomposition of wood, and makes the study of unaltered wood polymers impossible. To solve this problem, specimens were tested while being submerged in plasticizing solvents, reducing the glass transition of lignin and hemicellulose to a non-damaging or less damaging temperature. This technique was then employed to investigate the interaction of hydroxymethyl resorcinol (HMR) with wood polymers. The goal was to understand the fundamental mechanism for the improvement of wood-adhesive bond durability, with this treatment. Time and temperature dependence of molecular motions were systematically mapped using linear viscoelastic region (LVR) determination, dynamic thermal scans, and time temperature superposition (TTS) technique.

### Characterizing pMDI Reactions with Wood Cell Walls. Part I: High-Resolution Solution-State NMR Spectroscopy

Daniel J. Yelle, Physical Science Technician and Ph.D. Candidate, and *Joseph E. Jakes*, Student Training Engineer and Ph.D. Candidate, Materials Science Program, University of Wisconsin-Madison and USDA Forest Products Laboratory, Madison, Wisconsin, USA; *John Ralph*, Professor, Dept. of Biochemistry, University of Wisconsin-Madison, Madison, Wisconsin, USA; *Charles R. Frihart*, Head of Wood Adhesives Science & Technology, Performance Enhanced Biopolymers, USDA Forest Products Laboratory, Madison, Wisconsin, USA

**Biography:** Daniel J. Yelle is a Ph.D. Candidate in the Materials Science Program at the University of Wisconsin-Madison working with Professor John Ralph on new analytical techniques for exploring wood cell wall chemistry. His Ph.D. research project utilizes wood cell wall dissolution and solution-state NMR spectroscopy to investigate covalent bond formation between wood and adhesives. Additionally, he works in elucidating the chemistry of fungal decay mechanisms in wood cell walls. He is also a Physical Science Technician at the USDA Forest Products Laboratory. Previously, he was Process Improvement Coordinator, Potlatch, Bemidji Lumbermill; and Graduate Research Assistant, University of Maine. He received a B.S. in Wood Science from University of Minnesota-Twin Cities, M.S. in Forestry from the University of Maine, and Ph.D. in Forestry (expected graduation date is August 21, 2009) from the University of Wisconsin-Madison.

**Abstract:** Solution-state nuclear magnetic resonance spectroscopy (NMR) is a powerful tool for unambiguously determining the existence or absence of covalent chemical bonds between wood components and adhesives. Finely ground wood cell wall material dissolves in a solvent system containing dimethylsulfoxide-d6 and N-methylimidazole-d6, keeping wood component polymers intact and in a near-native state. Two-dimensional (2D) NMR experiments, using 13C-1H one-bond Heteronuclear Single Quantum Correlation on non-derivatized cell wall material from loblolly pine reveal details about the major cell wall polymers. This technique can determine covalent bond formation between cell wall polymers and wood adhesives. A monofunctional model compound of polymeric diphenylmethane diisocyanate (pMDI) was reacted with loblolly pine under moisture-controlled conditions to chemically modify the wood cell wall polymers. The modified loblolly pine was ball-milled, dissolved, and characterized via 2D NMR experiments. The NMR chemical shift data was then used to characterize urethanes formed between the pMDI model and the wood cell wall polymers. The data obtained allows us to determine whether covalent bonds form between loblolly pine and pMDI at different adhesive concentrations and moisture levels. Results show that high concentrations of the pMDI model react with the loblolly pine to form quantifiable urethane linkages with lignin sidechain units under dry conditions.

### Investigation of PF Adhesive Penetration in Wood by Micro X-ray Tomography

Fred A. Kamke, JELD-WEN Professor of Wood-Based Composite Science, and *Guenter Modzel*, Graduate Research Assistant, Dept. of Wood Science & Engineering, Oregon State University, Corvallis, Oregon, USA

**Biography:** Dr. Fred A. Kamke's research specialization is heat and mass transfer in wood and wood-based products, with emphasis on adhesion science, modeling, and the manufacture and performance of wood-based composite materials. He is the author of over 200 technical publications and presentations. Dr. Kamke has had primary responsibility for approximately $6 million in extramural research grants and contracts. He has taught college level courses in physical and mechanical properties of wood, wood anatomy, wood-based composite manufacture, drying of wood, wood and water relationships, durability of wood products, and adhesion of wood. Dr. Kamke also regularly teaches short courses developed for the wood-based composites industry. He is actively engaged in consulting activities in the areas of his research specialization. Dr. Kamke is a Fellow in the International Academy of Wood Science and a Past President of the Society for Wood Science & Technology. He received a B.S. from the University of Minnesota, and a Ph.D. Oregon State University.

**Abstract:** The performance of adhesive bonds in wood is believed to be influenced by the pattern of adhesive penetration. Wood is porous and highly permeable. However, the permeability is anisotropic and the pit network that connects adjacent cells inhibits the flow of liquids. Consequently, adhesive penetration into wood is highly variable.

Observation by light microscopy provides a two-dimensional view of the bondline, which gives some clues to the pattern of adhesive penetration. However, pathways of liquid adhesive movement during bond formation can only be speculated and the bondline is destroyed during preparation of the microscope specimen. SEM provides some three-dimensional perspective, but the pathway of adhesive flow is not revealed, and once again the specimen is destroyed. Micro x-ray tomography was performed on phenol-formaldehyde bonded specimens using facilities at the Advanced Photon Source at Argonne National Laboratory. Three-dimensional datasets were created and analyzed without destroying the specimen. The spatial resolution was 1.3 micron, which permitted pits to be observed. This paper describes the experimental technique and illustrates PF bondlines in Douglas-fir, southern pine, and yellow-poplar.

### 3D Characterization of Adhesives Penetration into Wood by Means of Synchrotron Radiation

*Philipp Hass*, Scientific Assistant and Ph.D. Student, ETH Zürich, Inst. for Building Materials, Zürich, Switzerland; *Marco Stampanoni*, Professor, Inst. for Biomedical Engineering, Paul Scherrer Inst., Villigen, Switzerland and ETH Zürich, Inst. for Building Materials, Zürich, Switzerland; *Anders Kaestner*, Research Assistant, Neutron Imaging & Activation Group, Paul Scherrer Inst., Villigen, Switzerland; *David Mannes*, Scientific Assistant and Ph.D. Student, and *Peter Niemz*, Professor and Head of Wood Physics Group, ETH Zürich, Inst. for Building Materials, Zürich, Switzerland

**Biography:** Philipp Hass is a Scientific Assistant and Ph.D. Student in the Wood Physics Group at ETH Zürich, Institute for Building Materials, Zürich, Switzerland.

**Abstract:** Adhesive penetration into wood plays a vital role in bond performance. Most investigations that have been carried out in the past dealt with this problem in a 2D-way by analyzing microtom sections, made from glued wood samples. Due to the risk of distorting results by sample preparation (modification of the glue line) and the loss of information by reducing investigations of a 3D-phenomenon – as adhesive penetration into wood – to 2D-analyses, the utilization of non-destructive 3D-testing methods seems to be the most appropriate for the assessment of adhesive penetration behavior into wood. 3D-investigations of glue lines have been carried out, using the synchrotron-microtomography facility TOMCAT at the Swiss Light Source (SLS) at the Paul-Scherrer-Institute, Villigen (CH). The penetration behavior of three adhesive systems – one-component polyurethane (PUR), polyvinylacetat (PVAC), and urea-formaldehyde (UF) – into beech wood (*Fagus sylvatica*) has been observed. This technique showed to be very suitable for the purpose of investigating glue lines in wood, as the pathway of the adhesive into the porous network of the wood could be tracked down and be visualized. Obvious differences between the systems were detected. PUR did penetrate much deeper into the wooden network than the other systems, leaving only little adhesive in the actual glue line. This behavior was due to the usage of prepolymers (unconditioned laboratory adhesives), which had a long curing time and no filling material to prevent the penetration. PVAC and UF did penetrate much lesser into the wood, leaving a distinct glue line between the two wooden adherends.

### Diffusion Processes at Glue Joints of Wood-Based Materials Evaluated by Means of Neutron Imaging

*Walter Sonderegger*, Scientific Assistant and Ph.D. Student, and *Peter Niemz*, Professor and Head of Wood Physics Group, ETH Zürich, Inst. for Building Materials, Zürich, Switzerland; *Eberhard Lehmann*, Group Leader of Neutron Imaging & Activation (NIAG), Paul Scherrer Inst., Villigen, Switzerland; *David Mannes* and *Stefan Hering*, Scientific Assistants and Ph.D. Students, ETH Zürich, Inst. for Building Materials, Zürich, Switzerland

**Biography:** Dr. Peter Niemz was Director of the Laboratory for Wood Physics & Non-Destructive Testing Methods at ETH Zürich from 1996 to 2002. He was awarded the title of Professor in 2002, and since then he has been the Head of the Wood Physics Group. After studying wood technology at the Faculty of Mechanical Engineering at the Dresden Technical University (TU Dresden), Dr. Niemz stayed there until 1985 as an Associate Scientist and Department Manager at the Institute of Wood Technology. During this period, he finished his dissertation in 1982 with the Ph.D. thesis "The influence of the structure on the rheological characteristics of timber materials". In 1985, he acquired his qualification as a university lecturer. From 1985 to 1992, Dr. Niemz worked as lecturer at the TU Dresden, representing the subjects of wood physics, timber materials, furniture manufacturing, and test engineering. From 1993 to 1996 he was, on behalf of the German Academic Exchange Service, Professor at the Universidad Austral de Chile in Valdivia (Chile) to develop the field of wood technology at the Faculty of Forest Sciences. In 1997, he was awarded the title of Professor of the Universidad Austral de Chile. The main focus of his work is on studying physical-mechanical characteristics of wood and timber materials as well as their structure-property relationships, and also on modeling them. He gives lectures in wood technology and timber materials. Since 2002, he has been a member of the IAWS (International Academy of Wood Science).

**Abstract:** The influence of glue joints on the diffusion processes is scarcely known. With conventional methods, the measurement is inexact due to the fact that a differentiation between the glue part and the wood-based material is difficult or impossible. Neutron imaging is a non-destructive testing method, which allows the visualization and quantification of the distribution of the glue and the absorbed water within the wooden sample. Investigations were made on various samples composed of wood and wood-based materials bonded with different wood adhesives. The specimens (two part of wood or wood-based material with a glue joint between it) were first dried and than exposed to a differential climate. The process of water absorption into the samples was measured with neutron imaging. Thereby, the accumulation of water within the specimen in front of the adhesive joint was visualized and the total amount quantified. Furthermore, the results were used to calculate the diffusion coefficients of each part of the specimen.

### Sophisticated Analyses of Low Emission Resins

*Wolfgang Kantner*, Laboratory & Product Development Manager, and *Johann Moser* and *Christian Heinemann*, Senior Product Development Chemists, Dynea Austria GmbH, Krems, Austria

**Biography:** Dr. Wolfgang Kantner is Laboratory & Product Development Manager, Dynea Austria GmbH, Krems, Austria. He is Head of product development for Composite Board Resins in Dynea Europe including several PD chemists, analytical engineers, and lab technicians; responsibility for renewal of the product portfolio according to the market and customer needs and support for product improvements together with their customers. He is also Head of the Laboratory in Dynea Austria concerning EHS matters, investments as well as the Quality Control department (since 2005). Previously, he was R&D Manager for Panelboard Resins in Dynea Europe, Dynea Austria; and Group Leader for R&D of Resins for the woodworking and surfacing industry, Krems Chemie (predecessor of Dynea Austria). He received a Dipl.Ing. (equivalent to Master degree for chemistry) and Ph.D. from the Technical University of Vienna, and M.S. in Innovation Management from Limak Johannes Kepler University Business School.

**Abstract:** Formaldehyde emissions have been a topic of many papers and conferences over a long time. After two decades of stable and accepted standards, we are in a time of change again. Boards with decreased formaldehyde emission that meet new standards like the Japanese F****, the Californian CARB, the voluntary European EPF-S, or IKEA's own standard are already or almost commercially available. For the resin producer, the usual analytical methods are no longer good enough to characterize the new type of resins. We are moving away from measuring simple physical or chemical measurements like gel times or Ford cup times. Instead, we are increasingly using analytical tools like rheology, ABES, DSC, GPC, HPLC, sticking methods, nanoindentation, etc. to describe the chemical and physical peculiarities of the new resins. Some of the methods give information of the neat resins, others describe the process of curing and finally there are methods to characterize the cured resin in a low emission panel. The paper will show the specifics and benefits of sophisticated analytical methods with examples from adhesives that are able to produce low emission boards. It will provide knowledge about the analytical possibilities that have been developed by one of the major European resin producers. As examples for the analytical methods, the paper will also provide some insight in the resin solutions that Dynea offers to its customers for producing particle or MDF boards with reduced formaldehyde emission.

### Characterization of pMDI Reacted Wood Part II: Nanoindentation

Joseph E. Jakes, Student Training Engineer and Ph.D. Candidate, and *Daniel J. Yelle*, Physical Science Technician and Ph.D. Candidate, Materials Science Program, University of Wisconsin-Madison and USDA Forest Products Laboratory, Madison, Wisconsin, USA; *James F. Beecher*, Supervisory Chemist, Analytical Chemistry & Microscopy Laboratory, USDA Forest Products Laboratory, Madison, Wisconsin, USA; *Donald S. Stone*, Professor, Dept. of Materials Science & Engineering, University of Wisconsin-Madison, Madison, Wisconsin, USA; *Charles R. Frihart*, Head of Wood Adhesives Science & Technology, Performance Enhanced Biopolymers, USDA Forest Products Laboratory, Madison, Wisconsin, USA

**Biography:** Joseph E. Jakes is a Ph.D. Candidate in the Materials Science Program at the University of Wisconsin-Madison. He is currently investigating structure-property relationships of both modified and unmodified wood cell walls. He is also a Student Training Engineer at the USDA Forest Products Laboratory. He received an M.S. from the University of Wisconsin-Madison.

**Abstract:** The mechanical properties of the pMDI reacted wood chemically characterized in Characterization of pMDI reacted wood Part I are assessed here in Part II using nanoindentation. We have developed a unique set of nanoindentation tools that allow us to measure local elastic modulus and hardness creep properties of both secondary cell wall laminae (SCWL) and compound corner middle lamellae (CCML). The creep measurement entails a technique called Broadband Nanoindentation Creep, which is able to probe the flow behavior across 4 decades of strain rate. Because conventional nanoindentation techniques are poorly suited for testing highly heterogeneous specimens, such as wood cells, we have developed a method for removing artifacts caused by heterogeneities. Nanoindentation was used to assess the properties of SCWL and CCML in unmodified wood and wood reacted with phenyl isocyanate at different moisture contents.

## SESSION 5B: Applications 2

### Dependence of Strength Values of Glued Wood Bonds on Specimen Geometry

Goran Mihulja, Assistant, *Hrvoje Turkulin*, Professor, and *Andrija Bogner*, Associate Professor, Faculty of Forestry, University of Zagreb, Zagreb, Croatia

**Biography:** Dr. Goran Mihulja is an Assistant at the Faculty of Forestry, University of Zagreb, Zagreb, Croatia. His responsibilities include six subjects – two major subjects: 1) glues and wood gluing, and 2) production technology for wood-based products – and four optional subjects: 3) CNC technique in wood-based production, 4) investigation of wood glued bonds, 5) selection of tools and machining parameters, and 6) projecting wood industry facilities. The second part of his responsibilities is scientific work in the laboratories on wood gluing process, surface preparation and modification, and investigation and development of testing procedures for glue bonds. He also works in the testing laboratory on testing of glues, glue bonds, and wood floor elements. He received a B.S., M.S., and Ph.D. from the University of Zagreb.

**Abstract:** This work is a contribution to methodological analysis and improvement of shear strength testing of glued wood bonds. Four types of specimens were compared in this study: two standard types of ISO 6238 specimen, standard EN 205 type and a non-standard, originally developed specimen for compressive shear (CS) testing. The standard tests utilize the specimen of such form and dimensions that the load supposedly induces the failure in the glue line. The shear strength measured in such way and the percentage of wood failure should suffice to determine the quality of glue bond. Testing result may depend on methodological factors such as the shape and dimensions of the specimen and the loading direction (compression or tension). These factors and their mutual interference may influence the starting point of failure, failure propagation path, and the substrate-affected causes of wood failure. The work aimed at selecting the testing method with least influence of those non-dominant factors on the testing result. Phototensiometry of the object raster was applied to monitor the distribution of the shifts (i.e. the deformities on the critical locations of the specimen surface). Dissipation of results and the analysis of the fracture morphology were utilized in evaluation of the testing methods. Four testing methods proved different in the range and accuracy of obtained results. The EN 205 method showed surprisingly poor results in terms of specimen deformations and scattering of values. The smaller ISO specimen and the originally developed CS specimen showed similarly reliable results. The work brings the indications about the optimization of the size, shape and structure of the specimen in order to obtain the reliable glue bond strength values.

### Glued Laminated Timber – Shear Test of Glue Lines

*René Steiger*, Group Leader, Timber Engineering, and Klaus Richter, Head, Wood Laboratory, Empa – Swiss Federal Laboratories of Materials Testing & Research, Dübendorf/Zürich, Switzerland

**Biography:** Dr. Klaus Richter is a Wood Scientist and Head of the Wood Laboratory, Swiss Federal Laboratories of Material Testing & Research (Empa), Dübendorf/Zürich, Switzerland. He graduated from the University of Hamburg in 1983. During his Ph.D. program, he spent 2 years at the Iberian Peninsula where he collaborated, among others, with the 'Instituto de Maderas del INIA' in Madrid. After defending his Ph.D. thesis at the University of Hamburg, he joined the Wood Lab of Empa in 1987 as a Research Scientist. He is involved in research and development and testing activities and knowledge transfer in the fields of wood technology and wood products application in building and construction, wood adhesion, surface treatment, timber modification, wood-polymer interaction, life-cycle assessment of building materials, and sustainability in building and construction. He was elected as Head of the Lab in 2003 and holds teaching assignments at the Technical Universities of Zürich (ETH Zürich) and Graz (TU Graz).

**Abstract:** Among other tests, shear tests of the glue lines are required in the course of quality control measures to be carried out in glulam plants. The procedures to be followed are given in different standards like for example EN 392:1995 and ISO 12579: 2006. In most of the standards, the method of applying shear stress to the glue line is only given by a principle scheme. Based on this scheme, a variety of test equipment has been produced by materials testing laboratories, glulam manufacturers and producers of adhesives. Depending on the actual construction of the test equipment as well as on the procedure of testing, the resulting stress in the glue line is not pure shear, but rather a combination of shear and normal stresses. In case of simultaneously acting shear stress and tensile stress perpendicular-to-the-grain, the shear strength values can drop dramatically, whereas compression stresses perpendicular-to-the-grain lead to an overestimation of the shear strength of the bond line. Being aware of these problems a prototype of a shear test device which ensures a clearly defined state of shear loading of the specimens has been developed in Switzerland and has been evaluated under practical conditions in glulam plants and under lab conditions. The paper will give an overview on existing methods for shear testing of wood. Starting from an explanation of the multiaxial stress situation by static equilibrium analysis, parameters, which influence the test results, are isolated. The prototype test set-up, which guarantees a clearly defined state of shear in the glue line is described together with extensive test results on the comparison of the prototype device with the established one in terms of shear strengths and percentages of wood failure.

### Hydrolitic Stability and Microstructure of Cured Urea-Formaldehyde Resins

Byung-Dae Park, Assistant Professor, and *Ho-Won Jeong*, Graduate Student, Dept. of Wood Science & Technology, Kyungpook National Univ., Daegu, Republic of Korea

**Biography:** Dr. Byung-Dae Park is an Assistant Professor in the Department of Wood Science & Technology, Kyungpook National Univ., Daegu, Republic of Korea. His responsibilities include teaching Wood Science to graduate and undergraduate students in the department, and conducting research on wood adhesives and wood-based composites. Previously, he was a Research Scientist, Korea Forest Research Institute; and 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 Laval University.

**Abstract:** As a part of abating formaldehyde emission of wood-based composite panels bonded with urea-formaldehyde (UF) resin adhesives, this study investigated microstructure of cured UF resins, using X-ray diffraction (XRD), field-emission-scanning electron microscopy (FE-SEM), energy dispersive X-ray analysis (EDXA), or atomic force microscopy (AFM). UF resins with lower formaldehyde/urea (F/U) mole ratios (1.2 or 1.0) showed a partially crystalline structure and spherical particles. The EDXA result provided distributions of chemical elements such as carbon, nitrogen, oxygen, or chloride in cured UF resins. As ammonium chloride content increased, the amount of oxygen decreased while that of the chloride increased. The EDXA also revealed three different types of chlorides in cured UF resins, and indi-

cated the distribution of residual acid as hydrochloric acid in cured UF resin. The observation of cured UF resins using AFM also showed a nodular structure, and etching treatment with dilute (0.1 N) hydrochloric acid to cured UF resin also showed hard and soft phases. These results partially explain crystalline structure of cured UF resin with lower F/U mole ratio.

### Study on the Bonding Property of Melamine and Urea-Formaldehyde Resin by Co-polymerization Modification

Libin Zhu, Associate Professor, and *Jiyou Gu*, Professor and Dean, College of Materials Science & Engineering, Northeast Forestry University, Harbin, P.R. China

**Biography:** Dr. Libin Zhu is an Associate Professor in the College of Materials Science & Engineering, Northeast Forestry University, Harbin, P.R. China. Her specialty is polymer materials and engineering. Her research interests include the adhesives used on wood and the manufacture of wood-based panels. She received a Bachelor, Master, and Ph.D. from Northeast Forestry University.

**Abstract:** Considering the industrial practice, an investigation was made of how the dosage of melamine affected bonding property of UF resin in different formaldehyde to first urea mole ratio (F/U1), and how adding steps of melamine, different mole ratio (F/U) affected bonding property with the unchanging of dosage of melamine. The results indicated that increasing the dosage of melamine, bonding strength was improved, formaldehyde emission was obviously reduced. Decreasing the formaldehyde to urea mole ratio (F/U) and adding the melamine by twice, it can decrease formaldehyde emission, but bonding strength can not be improved. When the melamine to total resin was 16%, the bonding strength of plywood reached national standard type I, formaldehyde emission meet near E0 standard.

### Adhesive Application of Liquefied Green and Mountain-Pine Beetle Infested Lodgepole Pine Barks

*Yong Zhao*, Ph.D. Student, and Ning Yan, Associate Professor, Faculty of Forestry, University of Toronto, Toronto, Ontario, Canada; *Martin W. Feng*, Senior Research Scientist and Project Leader, FPInnovations – Forintek Division, Vancouver, British Columbia, Canada

**Biography:** Dr. Ning Yan is an Associate Professor in the Faculty of Forestry, University of Toronto, Toronto, Ontario, Canada. Dr. Yan specializes in forest-based biomaterials science and composites, surface sciences of paper, and wood adhesives and adhesion. Currently, her research group is focused on developing novel environmental-friendly green bio-based composites and the next generation high valued paper-based products and producing green chemicals using renewable forestry biomass as feedstock. Dr. Yan is cross-appointed to the Department of Chemical Engineering & Applied Chemistry and is a founding member of the Centre for Biocomposites & Biomaterials Processing in the Faculty of Forestry. She is also an Associate Director of the Pulp & Paper Centre at the University of Toronto. Her areas of study include: Green bio-based composites and products from renewable forestry resources; Development of novel nanocellulose crystal based composite films; Green chemicals and adhesives from forestry biomass conversion; Design of light weight honeycomb core and MDF face sandwich panel for secondary applications; Inkjet deposition of bioactive agents on paper; and High yield pulp utilization in digital printing papers. Previously, she was a Visiting Scientist, FPInnovations – Forintek Division (during sabbatical); Visiting Scientist, Innventia (STFI-Packforsk AB) (during sabbatical); Assistant Professor, University of Toronto; Research Scientist, Xerox Corporation; and Research Scientist, Trojan Technologies. She received a B.Eng. from Southeast University, and Ph.D. from the University of Toronto.

**Abstract:** Liquefaction is an effective method to convert biomass materials as green chemical feedstock. In this study, mountain pine beetle infected Lodgepole pine bark and Green Lodgepole pine bark were liquefied in the presence of phenol catalyzed by sulfuric acid. The effect of reaction conditions such as liquefaction temperature, reaction time, phenol to bark ratio as well as catalyst loading on the residue ratio and free phenol have been investigated. The liquefied barks were used as synthetic phenol replacement to synthesis liquefied bark/phenol/formaldehyde adhesives. The molecular characteristics, thermal properties and curing behavior of the novel resin will be discussed. The results indicated that the reaction conditions significantly influenced the residue ratio and free phenol content of the liquefied barks. The properties of the resulting bark containing adhesives are presented.

### Development of Floor Tiles from Philippine Bamboos

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**Biography:** Dr. Marina A. Alipon is a Scientist I in the Department of Science & Technology (DOST), Forest Products R&D Inst. (FPRDI), College, Laguna, Philippines. Her responsibilities include research on wood science and technology including reports; she attends relevant meetings, conferences, and seminars; and renders technical assistance and consultancy to various clienteles specifically the timber industry sector. Previously, she was Supervising Science Research Specialist, Senior Science Research Specialist, Science Research Specialist II, Science Research Specialist I, all at FPRDI/DOST. She received a B.S. in Forestry from Gregorio Araneta University, and an M.S. in Forestry and Ph.D. in Forestry from the University of the Philippines.

**Abstract:** The study aimed to determine some important physical and mechanical properties of floor tiles from kauayan tinik (*Bambusa blumeana*) and giant bamboo (*Dendrocalamus asper*) glued with urea-formaldehyde (UF) and polyvinyl acetate (PVAc) with and without preservative treatments, and evaluate the performance of various preservatives on UF and PVAc's glued floor tiles from kauayan tinik and giant bamboo. Standard testing procedures and evaluation of bamboo floor tile's properties such as relative density, moisture content, hardness, thickness swelling, abrasive resistance and glue bond were followed. In contrast with the dry shear strength, the effect of preservatives was significant in the wet shear strength of UF- and PVAc-glued giant bamboo and kauayan tinik. Both UF-glued kauayan tinik and giant bamboo treated with deltamethrin exhibited the highest wet shear strength. While PVAc glued samples with and without preservatives exhibited higher dry shear strength than those of UF glued samples, the wet shear strength of the latter was higher than those of the former. UF glued kauayan tinik treated with either deltamethrin or borax and boric acid are preferable over the others in term of physical and mechanical properties, as well as cost of glue and preservative combinations.

## POSTER PRESENTATIONS

### POSTER 1 – Susceptibility of Thermally Modified Beech (*Fagus silvatica* L.) and Birch (*Betula pubescens* Ehrh.) to Gluing

Piotr Boruszewski, *Piotr Borysiuk*, *Mariusz Maminski*, and *Marek Grzeskiewicz*, Faculty of Wood Technology, Warsaw University of Life Sciences-SGGW, Warsaw, Poland

**Abstract:** One of the main disadvantages of wood is hygroscopicity resulting from its polar character. Interactions with water cause unwanted changes in moisture content, which occur as the result of sorption / desorption processes. These are the main reason of wood swelling and shrinkage. The thermal modification allows for the substantial weakening of these drawbacks. Unfortunately, thermal treatment can lead to the chemical changes in wood structure and alterations in polar character of the material. Subsequently, wetting by water or water-borne adhesives may be reduced. Susceptibility of thermally modified beech (*Fagus silvatica* L.) and birch (*Betula pubescens* Ehrh.) to gluing with two commercial amino resins (MUF, MF) and a two-component PUR adhesive were investigated. Both wood species were modified in an overheated steam according to two regimes: 1) 1 hour, 160°C, and 2) 2 hours, 190°C. Shear strengths of the joints were determined according to EN 205:1991.

### POSTER 2 – Bonding Quality of PE-Bonded Beech Plywood made from Thermally Modified Veneers

Piotr Borysiuk, *Mariusz Maminski*, *Piotr Boruszewski*, and *Marek Grzeskiewicz*, Faculty of Wood Technology, Warsaw University of Life Sciences-SGGW, Warsaw, Poland

**Abstract:** Beech veneers were subjected to superheated steam treatment at temperature 195ºC, for: 0.5, 1.0, or 1.5 hour. Veneer modification was carried out in laboratory conditions. Mechanical and physical properties of veneers were determined in order to choose the low-destructive parameters. The modified and unmodified veneers were used in manufacturing 3-ply plywood in laboratory scale with PE or UF as binder. The bonding quality was assessed by dry and wet shear strength measurements.

## POSTER 3 – Hyperbranched Macromolecules as Modifiers of the Urea-Formaldehyde Resins

Mariusz Maminski, Faculty of Wood Technology, Warsaw University of Life Sciences-SGGW, Warsaw, Poland; *Pawel Parzuchowski*, Faculty of Chemistry, Warsaw University of Technology, Warsaw, Poland; *Piotr Borysiuk* and *Piotr Boruszewski*, Faculty of Wood Technology, Warsaw University of Life Sciences-SGGW, Warsaw, Poland

**Abstract:** Four hyperbranched polymers were used as modifiers of a commercial urea-formaldehyde resin at the glue-mix preparation step. Three hyperbranched polyglycerols and one polyester with different core and shell chemical structure were examined. The influence of blending with respective compounds on the mechanical and physio-chemical properties of the bondline was studied. In all cases, it was found that the bondline strength of the standard lap shear specimens remained intact when dry, but significantly decreased after water soaking. It has also been shown that hydroxyl-terminated hyperbranched molecules can effectively bind free formaldehyde and reduce its emission from the formaldehyde-containing materials.

## POSTER 4 – Characterization of the Two Different Phases in Urea-Formaldehyde Resins

João Ferra, Ph.D. Student, Laboratory of Process, Environment & Energy Engineering, FEUP-LEPAE, Porto, Portugal; *Jorge Martins*, Professor, Laboratory of Process, Environment & Energy Engineering, FEUP-LEPAE, Porto, Portugal and Dept. of Wood Engineering, Polytechnic Inst. of Viseu, Viseu, Portugal; *Adélio M. Mendes*, Professor, Laboratory of Process, Environment & Energy Engineering, FEUP-LEPAE, Porto, Portugal; *Mário R. Costa*, Professor, Laboratory of Separation & Reaction Engineering, LSRE, Porto, Portugal; *Luisa H. Carvalho*, Professor, Laboratory of Process, Environment & Energy Engineering, FEUP-LEPAE, Porto, Portugal and Dept. of Wood Engineering, Polytechnic Inst. of Viseu, Viseu, Portugal; *Fernão D. Magalhães*, Professor, Laboratory of Process, Environment & Energy Engineering, FEUP-LEPAE, Porto, Portugal

**Abstract:** Urea-formaldehyde (UF) resins are still the most widely used adhesives in the manufacture of wood-based panels, mostly due to their high reactivity, low cost and excellent adhesion to wood. However, there is a lack of studies relating the operating conditions of the polymerization reactors and the properties of these resins. Moreover, it is not fully understood the impact of their formulation on the performance of wood-based panels manufactured with these resins. In the near future, companies will face the need to produce still lower formaldehyde emission resins, with emissions close to the level of natural wood. In order to achieve this goal, it is necessary to optimize the process and improve its control. An important issue concerning the nature of UF resins has to do with their biphasic structure: water soluble oligomers coexist with a swollen colloidal phase, and the role of each phase in the adhesion and resin-ageing processes is ill-defined. The main goal of the present investigation is to put into evidence the physical and chemical differences between the two phases and their impact on the bonding process. The results of the separation by centrifugation of two phases showed that this technique did not separating totally. Some differences of the properties of each phase have been detected using analytical techniques (GPC/SEC, DSC and particle size distribution). The results of tests carried out to evaluate adhesive performance of each phase and resin showed that the highest tensile shear strength was obtained for samples bonding with sediment glue.

## POSTER 5 – Visualization of Wood Fiber-Adhesive Interactions of Adhesive Formulations Containing Bio-Based Components

Warren J. Grigsby and *Armin Thumm*, Scientists, Scion, Rotorua, New Zealand

**Abstract:** Recently, there has been a resurgent interest in the commercial utilization of renewables to substitute in part- or full petrochemical components in adhesive and resin formulations. The use of biomaterials in adhesive formulations can impact on the physical characteristics of the adhesive or resin such as differing wetting characteristics and product performance. We have been investigating the fundamental fiber-adhesive interactions of various bio-derived components substituted into existing or modified adhesive formulations. Reported are results from fluorescence microscopy analysis characterizing the wetting behaviors and fiber-adhesive interactions of some biomaterials when formulated as an adhesive and processed into MDF wood composite panel. The results will be contrasted with those of UF resin, the adhesive typically used in MDF manufacture.

## POSTER 6 – Bonding of Plantation Teak Wood with Various Adhesives

Christian Hansmann, Key Researcher, Wood Materials Technology, Wood Kplus – Competence Centre for Wood Composites & Wood Chemistry, Linz, Austria; *Robert Stingl*, Junior Researcher, Dept. of Material Sciences & Process Engineering, BOKU – University of Natural Resources & Applied Life Sciences, Vienna, Austria; *Hermann Pleschberger*, Junior Researcher, and *Ulrich Mueller*, Area Manager, Wood Materials Technology, Wood Kplus – Competence Centre for Wood Composites & Wood Chemistry, Linz, Austria, and Dept. of Material Sciences & Process Engineering, BOKU – University of Natural Resources & Applied Life Sciences, Vienna, Austria

**Abstract:** Together with other species, plantation teak wood gains in importance in Europe. Most adhesives in Europe are optimized for Norway spruce and Beech wood. While Norway spruce is one of the most important commercial wood species in Europe, Beech wood is demanded to test tensile shear strength according to the European standard EN 302. In general, other wood species used for interior and furniture applications are bonded with PVAc glues. Information about the bonding performance of different adhesives applied for hardwood species is lacking. Especially for adhesives accredited for load bearing constructions, no detailed information is available concerning mechanical performance as well as stability at increased temperature or humidity. Scarf joints corresponding to the older DIN 53 253 bonded with various adhesives were tested at room temperature and at 65°C. The results proved that PVAc together with emulsion polymer isocyanate (EPI) adhesives perform better than aminoplastic (MUF) and resorcinol resins (PRF) as well as polyurethane (PUR) at room temperature, whereas PVAc glues are strongly affected by increased temperature. While EPI, MUF, and PRF showed acceptable mechanical properties at increased temperature, these adhesives did not prove high stability in the delamination tests according to EN 391. However, PRF and MUF performed better than EPI. The results showed that Teak can be properly bonded with PVAc glues. However, at increased temperature and at higher moisture content these glues have to be replaced with PRF or EPI resins. Nevertheless, the results showed that bonding of Teak for load bearing constructions is crucial.

## POSTER 7 – Observation of Adhesive Penetration into Wood by Laser Scanning Microscopy

*Naruhito Hori*, Assistant Professor, and Akio Takemura, Associate Professor, University of Tokyo, Tokyo, Japan

**Abstract:** The present study advances the method established by Kamke et.al. to quantify the adhesive penetration into wood substrate. Using confocal laser scanning microscopy with splitting the reflected fluorescence allows us to distinguish the adhesive clearly from wood. The fine digitized images are transformed into the frequency distribution diagram of the amount of penetrating adhesive as a function of distance from the center of the bond line. This distribution is approximated by an expression composed of two terms of the standard normal distribution. One term of the distribution is attributed to the adhesive layer itself and the penetrated adhesives near the adhesive-wood boundary face, the other is assignable to the deeply penetration through the vessel perforation of hardwood.

## POSTER 8 – Monitoring of Wood-Adhesive Interactions during Cure by ARES G2 Rheometer

Milan Sernek, Associate Professor, and *Mirko Kariz*, Graduate Assistant, Dept. of Wood Science & Technology, University of Ljubljana, Ljubljana, Slovenia

**Abstract:** The ARES-G2 is a new designed strain controlled rheometer from TA Instruments. Separate motor and transducer (SMT) construction, air bearings, separate test station, and electronics box and new Trios software make measurements easier, accurate, and more reliable. The ARES-G2 rheometer measures viscosity and viscoelastic properties of fluids, semi-solids, and solids. It provides information about the material's viscosity as a function of shear rate or stress, time, temperature; or viscoelastic properties with respect to time, temperature, frequency, stress, and strain. Oscillation tests carried out with the rheometer can provide a total curing profile of an adhesive, which is placed on parallel plate geometry that oscillates with small amplitude at defined frequency. Standardized aluminum and steel plates can be replaced with plates from wood, which allow determining interactions between wood and adhesive during hardening. The cure of the adhesive is carried out in the controlled environment at either isothermal conditions or at precise heating rate. The viscoelastic parameter of the adhesive during cure can be obtained in terms of the elastic (storage)

modulus (G'), the viscous (loss) modulus (G") and tan δ (G"/G'). These parameters can provide valuable information about the cure behavior of the adhesive such as gelation and vitrification.

### POSTER 9 – Development of Static and Dynamic Measurements of Organic Acids Emitted from Wood and Adhesives for Wood

*Kensuke Kawarada*, Chief Researcher, and *Keiko Kurita*, Researcher, Tokyo Metropolitan Industrial Technology Research Inst., Tokyo, Japan; *Masaharu Ohmi*, Associate Professor, Tokyo University of Agriculture & Technology, Tokyo, Japan

**Abstract:** It is well known that organic acids (formic and acetic acids) in the indoor air caused to decompose cultural asset made of metal and inorganic pigment. However, there was few knowledge about emission behaviors from wood and adhesives for wood. Therefore, it is important to clarify the emission mechanism of organic acids from wood and adhesives, and the concentration in air or emission factors of organic acids from wood and adhesives were measured by static and dynamic methods. With static method, glass desiccator method was used to determine the concentration of emitted organic acids. Water put into desiccator was analyzed by ion chromatography to detect formic and acetic acids. In case of dynamic method, small chamber method was used to determine the emission factor of organic acids. Charcoal and graphite carbon tubes were used to trap organic acids. The graphite carbon tube was more suitable for measurement of organic acids analyzed by ion chromatograph than the charcoal tube. Some softwood used as the building material for the cultural asset emitted high concentration of acetic acid. The concentration of the organic acids decreased with the decrease of moisture content of wood and wood-based material. The kiln dry process affected on the emission of organic acids from solid wood. Poly vinyl acetate emulsion adhesive (PVAc) released acetic acid higher than other adhesives such as urethane resin and water-based polymer-isocyanate adhesive (API).

### POSTER 10 – Protein-based Binders for Particleboards

*Sara Khosravi*, Ph.D. Student, and *Mats Johansson*, Professor, Dept. of Fibre & Polymer Technology, Royal Institute of Technology, Stockholm, Sweden; *Farideh Khabbaz*, Senior Research Chemist, Casco Adhesives AB, Stockholm, Sweden; *Petra Nordqvist*, Ph.D. Student, Dept. of Fibre & Polymer Technology, Royal Institute of Technology, Stockholm, Sweden

**Abstract:** Particleboards are wood composites employed in several applications, ranging from furniture to construction. Today, the most commonly used binders for particleboards are formaldehyde-based adhesives. However, these adhesives are petroleum based and with increasing environmental awareness, there is a growing interest for renewable raw materials, such as vegetable proteins. The aim of the present study was to evaluate soy protein isolate (SPI) and wheat gluten (WG) as adhesives in particleboard applications. Furthermore, parameters regarding the formulation of an adhesive and the gluing process were investigated, while the press parameters were kept constant. The proteins were applied as dispersions, dry protein powders, or as dispersions in combination with dry protein powder. Regarding the formulation of dispersions the considered factors were: the temperature (room temperature, 50 or 80°C) during the preparation of the dispersions, and the time (1, 3, or 5 h) for preparing the dispersions. The gluing performance was evaluated by measuring the internal bond and swelling values according to the European standards SS-EN 319 and SS-EN 317. The results reveal that it is preferable to use dispersion rather than a combination of a dispersion and dry protein powder. Additionally, there is a clear difference between the proteins; it appears that SPI is superior to WG regarding the water resistant properties of the boards. The explanation to these differences is suggested to be found in the chemical composition difference of these proteins.

### POSTER 11 – Environmental Performance on Indoor Air Pollutant of Wood-Based Flooring Bonded with Tannin/PVAc Hybrid Adhesives for Surface Bonding

*Sumin Kim*, Assistant Professor, Dept. of Architecture, Soongsil University, Seoul, Republic of Korea

**Abstract:** The objective of this research was to develop environment-friendly adhesives for face fancy veneer bonding of engineered flooring using the natural tannin form bark in the wood. The natural wattle tannin adhesive were used to replace UF resin in the formaldehyde-based resin system in order to reduce formaldehyde and volatile organic compound (VOC) emissions from the adhesives used between plywoods and fancy veneers. PVAc was added to the natural tannin adhesive to increase viscosity of tannin adhesive for surface bonding. For Tannin/PVAc hybrid adhesives, 5, 10, 20, and 30% of PVAc to the natural tannin adhesives were added. Tannin/PVAc hybrid adhesives showed better bonding than the commercial natural tannin adhesive with a higher level of wood penetration. The initial adhesion strength was sufficient to be maintained within the optimum initial tack range. The standard formaldehyde emission test (desiccator method), Field and Laboratory Emission Cell (FLEC) and VOC analyzer were used to determine the formaldehyde and VOC emissions from engineered flooring bonded with commercial the natural tannin adhesive and Tannin/PVAc hybrid adhesives. By desiccator method and FLEC, the formaldehyde emission level of each adhesive showed the similar tendency. All adhesives satisfied the $E_1$ grade (below 1.5mg/L) and $E_0$ grade (below 0.5mg/L) with UV coating. VOC emission results by FLEC and VOC analyzer were different with the formaldehyde emission results. TVOC emission was slightly increased as adding PVAc.

### POSTER 12 – Bio-modified PVA Adhesives with Extended Assembly Time

*Yuan Liu*, Senior Product Development Chemist, *Mark Vrana*, Senior Director of Technology & Quality, *Michelle Tobbe*, Technical Director, Wood Adhesives, *Chuck Shuster*, Senior Research Associate, and *Jeffrey Shumaker*, Senior Technical Specialist, Franklin International, Columbus, Ohio, USA

**Abstract:** In recent years, cross-linking polyvinyl acetate (xPVA) adhesives have attracted increased interest in the hardwood plywood industry due to the ever-tightening formaldehyde emission regulations. For xPVA to be widely accepted in the hardwood plywood industry, the relatively short assembly time and high cost compared to urea-formaldehyde adhesives must be overcome. Franklin International developed one-part stable xPVA adhesives containing 25% renewable materials. The combination of chemically modified soy protein with xPVA polymer not only makes the adhesive more cost-effective and environmentally friendly, also increases the assembly time of adhesives. The bio-modified xPVA adhesives have demonstrated mechanical performances and storage stability comparable to conventional xPVA.

### POSTER 13 – Carboxymethylcellulose Acetate Butyrate as a Wood Adhesive

*Jesse L. Paris*, Graduate Research Assistant, and *Charles E. Frazier*, Thomas M. Brooks Professor, Dept. of Wood Science & Forest Products, and Director, Wood-Based Composites Center, Virginia Tech, Blacksburg, Virginia, USA

**Abstract:** Carboxymethylcellulose acetate/butyrate mixed esters, CMCAB, was developed by Eastman Chemical Company for automotive coatings. High solids content, water-based dispersions are created by mixing CMCAB organic solutions in water; a portion of the carboxylic acid groups are neutralized with an amine, such as N-N-dimethylethanolamine. These water-based CMCAB dispersions are being studied as potential wood adhesives. This system holds promise because it is both renewable and formaldehyde-free. Presently, research is focused upon the dynamic mechanical analysis of films cast from both organic solutions and from water dispersions. Effects of different solvents and neutralizing amines are being compared. Early results indicate that thermal properties are affected by the type of solvent and amine. Initial adhesion results from mode 1 fracture test data will also be presented.

### POSTER 14 – Dynamic Mechanical Analysis: A Novel Method to Screen Potential Wood Adhesive Coupling Agents

*Joshua A. Hosen*, Graduate Research Assistant, and *Charles E. Frazier*, Thomas M. Brooks Professor, Dept. of Wood Science & Forest Products, and Director, Wood-Based Composites Center, Virginia Tech, Blacksburg, Virginia, USA

**Abstract:** Dilute alkaline solutions of hydroxymethyl resorcinol (HMR) are effective coupling agents for wood bonding; HMR dramatically increases durability against moisture exposure. Recent studies in our group demonstrated that HMR causes an increase in the Tg of lignin, the amorphous wood polymer that binds cellulose fibrils. The analysis involves dynamic torsion while the wood specimen is immersed in a plasticizer like dimethylformamide. This solvent submersion DMA simplifies observation of the lignin Tg, which in dry wood is accompanied by thermal degradation of the sample. HMR's effect on the lignin Tg suggests that careful observation of this transition might provide a simpler method of screening chemical treatments as possible wood adhesion coupling agents. Currently, wood coupling agents are evaluated with a very laborious ASTM method (D2559).

Consequently, the objective of this work is to improve the technique of submersion torsion wood DMA, and to determine if such DMA is effective for predicting the coupling agent potential of other chemical treatments. To date, the solvent submersion-torsion DMA has been learned, and observations of the HMR/lignin Tg effect have been replicated. Presently, new chemical treatments are being evaluated for their effect on the lignin glass transition, all in the hopes of developing novel wood adhesion coupling agents that are more commercially feasible than HMR.

### POSTER 15 – Abating the Formaldehyde Emission of Urea-Melamine-Formaldehyde Resin Bonded Medium Density Fiberboards

*Jong-Young Park*, Senior Research Scientist, *Sang-Min Lee*, Research Scientist, and *Sang-Bum Park*, Senior Research Scientist, Korea Forest Research Inst., Seoul, Republic of Korea

**Abstract:** This study was done to examine the effects of formaldehyde/urea (F/U) mole ratio and melamine content on the properties of UMF resin adhesives. Urea-melamine-formaldehyde (UMF) resins were synthesized and used for manufacturing medium density fiberboards (MDF). As increased F/U molar ratio, solids content of resin increased. Physical properties and storage stability of resins tended to improve slightly when the final pH of resin was 8.5. At the same F/U molar ratio, free formaldehyde contents and gel time of resins were decreased as increased of melamine content. Chemical structures of resins were proposed from the results of 13C-NMR and FT-IR analysis. Formaldehyde emissions of MDF prepared with UMF resins were decreased as melamine contents of resin increased.

### POSTER 16 – The Role of Lignin in a Furfuryl Alcohol-Lignin Adhesive

*Cheryl Leger*, Student, Wood Science & Technology Centre, University of New Brunswick, Fredericton, New Brunswick, Canada; *M.H. Schneider*, President, Woodtech Inc., Fredericton, New Brunswick, Canada; *Felisa Chan*, Research Scientist, Wood Science & Technology Centre, University of New Brunswick, Fredericton, New Brunswick, Canada

**Abstract:** The role of lignin in a furfuryl alcohol-lignin adhesive was investigated using differential scanning calorimetry (DSC), thermogravimetric analysis (TGA), and nuclear magnetic resonance (NMR) spectrometry. Lignin whole and lignin fractionated by polarity were used throughout the study. Vanillin was used as a model compound. NMR results yielded evidence of reaction, primarily through line broadening in the regions of interest. Thin layer chromatography found a product of furfuryl alcohol-vanillin reaction with unique Rf value, indicating a compound unique from either parent. It was concluded that lignin reacted with furfuryl alcohol. DSC results found that lignin did not self-react under the conditions of study. Activation energies at 1%, 10%, and 50% conversion, using the Vyazovkin method, were lower for adhesive reactions containing the principal lignin fraction than for catalyzed furfuryl alcohol. Adhesive reactions typically exhibited more pronounced exotherms than catalyzed furfuryl alcohol and at temperatures slightly lower and slightly higher than those of catalyzed furfuryl alcohol. TGA demonstrated the greater thermal resistance of the adhesive to catalyzed furfuryl alcohol, lignin, and catalyzed lignin. Thermal analysis concluded that lignin not only reacts with furfuryl alcohol, but is a comonomer in the adhesive. Lignin was concluded to be not only a reactive component, but also a necessary comonomer without which a very different, and inferior, adhesive resulted. Contrary to conventional thinking, it was found that it is possible to include lignin in an adhesive formulation without greatly sacrificing either curing speed or bonding properties. Results prompted the proposal of a reaction mechanism.

### POSTER 17 – Nanoindentation for Mechanical Characterization of Wood Adhesive Bonds

*Johannes Konnerth*, Assistant Professor, and *Wolfgang Gindl*, Associate Professor, Dept. of Material Sciences & Process Engineering, BOKU – University of Natural Resources & Applied Life Sciences, Vienna, Austria

**Abstract:** Nanoindentation is presented as a useful tool in wood adhesive research. Mechanical characterization of individual bond line regions, namely adhesive bond line, wood cell walls (S2) in the interphase region, and reference cell walls can be performed on the microscale. Results from nanoindentation measurements of bond regions with different adhesive systems (polyurethane, phenol resorcinol formaldehyde, melamine urea formaldehyde, and polyvinyl acetate) show significant differences between the adhesive systems used. Micromechanical investigations on different adhesive films exposed to either temperature or water should give further explanation of the macromechanical behavior of bonds in corresponding ambient.

### POSTER 18 – Nanoindentation Creep Properties of the S2 Cell Wall Lamina and Compound Corner Middle Lamella

*Joseph E. Jakes*, Student Training Engineer and Ph.D. Candidate, Materials Science Program, University of Wisconsin-Madison and USDA Forest Products Laboratory, Madison, Wisconsin, USA; *Charles R. Frihart*, Head of Wood Adhesives Science & Technology, Performance Enhanced Biopolymers, and *James F. Beecher*, Supervisory Chemist, Analytical Chemistry & Microscopy Laboratory, USDA Forest Products Laboratory, Madison, Wisconsin, USA; *Donald S. Stone*, Professor, Dept. of Materials Science & Engineering, University of Wisconsin-Madison, Madison, Wisconsin, USA

**Abstract:** Bulk wood properties are derived from an ensemble of processes taking place at the micron-scale, and at this level the properties differ dramatically in going from cell wall layers to the middle lamella. To better understand the properties of these micron-scaled regions of wood, we have developed a unique set of nanoindentation tools that allow us to measure local elastic modulus and hardness creep properties. The creep measurement entails a technique called broadband nanoindentation creep (BNC), which is able to probe the material flow behavior across 4 decades of strain rate. Because conventional nanoindentation techniques are poorly suited for testing highly heterogeneous specimens, such as wood cells, we have developed a method for removing artifacts caused by heterogeneities. After these artifacts are removed, the elastic modulus can be determined in the usual way. In loblolly pine, we measure the properties of the S2 cell wall lamina (SCWL) and the compound corner middle lamella (CCML) of both untreated and ethylene glycol treated wood. The ethylene glycol plasticizes both the SCWL and CCML.

### POSTER 19 – Rapid Cold-Curing Polymer for Lignocellulosic Composites from Phenol-Formaldehyde and Methylene Diisocyanate

*Robert A. Haupt*, Graduate Research Assistant, Dept. of Wood Science & Forest Products, Virginia Tech, Blacksburg, Virginia, USA

**Abstract:** Effective and novel cold curing adhesives for lignocellulosic composites have been known for quite some time, but are limited by drawbacks such as cost or exotic raw materials. A simple system from another approach has been developed using commonly known raw materials in a novel combination. The system comprises a phenol-formaldehyde resin combined with a polyurethane catalyst, and methylene diisocyanate combined with a phenol-formaldehyde cure accelerator. When the two components are combined, they polymerize rapidly via cross-catalysis and cross-acceleration. PF monomer prepared at ambient temperatures and a commercial type PF OSB resin were used in combination with MDI, using tin(II) chloride or ammonium hydroxide as polyurethane catalysts and propylene carbonate as the PF accelerator. Curing reactions were monitored by gel time at ambient temperature and differential scanning calorimetry. The results showed that polymeric material forms rapidly at temperatures between 20-25°C in less than 100 seconds. The results also indicate that the synergistic effect of the catalyst and accelerator would permit reduced consumption of the relatively expensive MDI and PF accelerator system constituents. This discovery could prove significant for reducing adhesive costs, pressing time, and pressing temperatures for lignocellulosic composites.

### POSTER 20 – The Use of Furfural and Soy Protein Isolate in Phenolic Resin for Bonding Wood

*Emmanuel Lépine*, Ph.D. Student, and *Bernard Riedl*, Senior Professor, Dept. of Wood Science, Laval University, Quebec City, Quebec, Canada; *Xiang-Ming Wang*, Senior Research Scientist and Group Leader, FPInnovations - Forintek Division, Quebec City, Quebec, Canada

**Abstract:** The main objective of the poster is to enhance the value of furfural and soy protein isolate, respectively, as crosslinker and copolymer for bonding wood. Furfural is used to replace formaldehyde in a phenol-furfural-formaldehyde resin with different ratios of formaldehyde to be used, while the soy protein isolate are first crosslinked with the furfural and then mixed with the phenol-furfural-formaldehyde resin. Different ratios of both polymers are used in an alkaline medium. The ASTM D 905 has been preferred to test the different adhesives. Shearing tests have been performed using solid pieces of *Acer Saccharum*. Different times of cooking have been tried in order to define the impact of CHOH content and soy protein isolate

content on reactivity and shearing resistance. The results tend to prove that a certain amount of CHOH must be used to diminish the amount of energy used for resin polymerization. This amount is however reaching a maximum which allows to reduce the use of CHOH and enhance the value of furfural as an effective crosslinker. The best results concerning the soy protein isolate were obtained with the 20% content compared to the 40% content. However, the resin containing 40% of soy protein isolate gave acceptable results, considering the fact that 40% is a high level of replacement.

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