

BIOGRAPHIES AND ABSTRACTS

8th International Conference on
WOODFIBER-PLASTIC
Composites *(and other natural fibers)*

May 23-25, 2005
Monona Terrace Community & Convention Center
Madison, Wisconsin, USA

Hosted by the USDA Forest Service, Forest Products Laboratory in cooperation with the American Institute of Chemical Engineers, the Norwegian University of Science and Technology, the University of Tennessee in conjunction with Oak Ridge National Laboratory, the University of Toronto and Materials & Manufacturing Ontario, and the Forest Products Society. The Monday evening reception is sponsored, in part, by Luzenac America, Inc. Specialty Minerals Inc. is sponsoring speaker travel. Ontario Sawdust Supplies Ltd., wood flour supplier, is sponsoring the student contest.

PLANNING COMMITTEE

Conference Chair

Craig M. Clemons
Materials Research Engineer
Forest Products Laboratory
USDA Forest Service
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Dr. Craig Clemons is a Materials Research Engineer in the Performance-Engineered Composites Group at the USDA Forest Products Laboratory (FPL) in Madison, Wisconsin. He received a B.S. in Chemical Engineering, M.S. in Forestry, and Ph.D. in Materials Science from the University of Wisconsin-Madison. For the past 15 years, he has worked at FPL developing composite materials from plastics, additives, and wood or other natural fibers. His areas of interest lay both in the materials science and processing of these composites.

Committee Members & Session Moderators

John J. Balatinecz
Professor Emeritus
Faculty of Forestry
University of Toronto
Toronto, Ontario, Canada



Dr. John Balatinecz is Professor Emeritus in the Faculty of Forestry, University of Toronto, Toronto, Ontario, Canada. His research interests include wood composites, woodfiber-plastic composites, recycling, and product development. He specializes in defining the relationships between raw material and process parameters versus product properties and performance. Much of his work has concentrated on wood quality and fiber morphology variation, the relationship between tree growth and wood quality, and the influence of fiber properties on products. He has recently become involved in the green certification process. He received a B.S. in Forestry from the University of British Columbia, an M.S. in Forestry from the University of Washington, and a Ph.D. from the University of Toronto.

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



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

Daniel F. Caulfield
Research Chemist
Forest Products Laboratory
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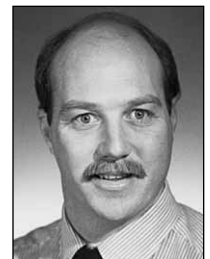
Dr. Daniel Caulfield is a native of New York City and received a B.S. in Chemistry from Brooklyn College. He received a Ph.D. in Physical/Polymer Chemistry from the Polytechnic Institute of Brooklyn (now Polytechnic University of New York) and was a Post-Doctoral Associate at Cornell University. He has been a Research Chemist at the USDA Forest Products Laboratory in Madison for 40 years. His fields of research interest are materials science; particularly structure/properties relationships in polymers, paper and fiber composites, and has written 100 technical articles largely in the fields of moisture interaction with paper, and the surface interactions and structure of fiber/plastic composites. He is a member of the American Chemical Society (Cellulose, Paper and Textile Division and Polymer Division Inc.), TAPPI (Paper Physics Committee), Materials Research Society, and the Society of Plastics Engineers. He is the recipient of the 1986 L.J. Markwardt Award for Wood Engineering Research, awarded by the Forest Products Society. In 1984, he was elected a Fellow of the International Academy of Wood Science. Since 1994, he has served as associate technical editor for the *Journal of Pulp and Paper Science*. He has served as a member of the organizing committee for all eight of the Conferences held in Madison on Woodfiber-Plastic Composites.

Karl R. Englund
Research Engineer
Wood Materials & Engineering Laboratory
Washington State University
Pullman, Washington, USA



Dr. Karl Englund is a Research Engineer in the Wood Materials and Engineering Laboratory at Washington State University, Pullman, Washington. As the technical manager of composites, his primary responsibilities include coordinating research and development jobs with industrial clients and a variety of federal and state funded research projects with a majority of the projects emphasizing WPCs. He received a B.S. in Forestry and M.S. in Wood Science from West Virginia University, and a Ph.D. in Civil Engineering from Washington State University.

Robert H. Falk
Research Engineer
Forest Products Laboratory
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Dr. Robert Falk is a Research Engineer at the USDA Forest Products Laboratory in Madison, Wisconsin. He performs research on the development of value-added building products from wood waste materials. This work includes the development of reuse options for salvaged lumber and timber as well as the development of composites from waste natural fibers and waste thermoplastics. In addition to developing a basic understanding of the engineering properties of these materials, Dr. Falk is active in helping develop the engineering property and engineering design standards necessary to facilitate their widespread use in construction applications. He is a professionally registered engineer and received a B.S. in Civil Engineering from California Polytechnic State University, an M.S. in Civil Engineering from Michigan Technological University, and a Ph.D. in Structural Engineering from Washington State University.

David P. Harper
Assistant Professor
Forest Products Center
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Dr. David Harper is an Assistant Professor at the Forest Products Center, University of Tennessee, Knoxville, Tennessee. His research interests include wood/polymer interfaces, wood composites, and materials from renewable resources. He received a B.A. in Physics from West Virginia University, and an M.S. and Ph.D. in Civil Engineering from Washington State University.

John C. Hermanson
Research Engineer
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Dr. John Hermanson is a Research Scientist at the USDA Forest Products Laboratory in Madison, Wisconsin. His responsibilities include research on engineering physics of wood and wood-based composites. The approach used to examine the wood and wood-based composites is a data-driven inverse characterization of continuum degrading systems. Previously, he was a Research Scientist at the Wood Materials and Engineering Laboratory, Washington State University. He received a BSCE and MSCE from the University of Washington, and a Ph.D. from the University of Wisconsin.

Rebecca E. Ibach
Research Chemist
Forest Products Laboratory
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Dr. Rebecca Ibach is a Research Chemist in the Modified Lignocellulosic Materials Project at the USDA Forest Products Laboratory in Madison, Wisconsin. Her research is in chemically modifying solid wood and wood-based composites by lumen-filling and/or cell wall bonding chemistries to protect wood (from moisture, UV, and biological deterioration) and to improve its properties (i.e. mechanical, dimensional stability, and hardness). She received a B.S. from St. Norbert College, and a Ph.D. from the University of Wisconsin-Madison.

Kristiina Oksman
Professor
Department of Engineering
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Dr. Kristiina Oksman is a Professor in the Department of Engineering Design and Materials, Norwegian University of Science and Technology, Trondheim, Norway. Her responsibilities include teaching, supervising Ph.D. students, project leader for research projects, board member for SINTEF, NTNU material strategy, etc. She received an M.S. in Material Science & Engineering and a Ph.D. from Luleå University of Technology. Previously, she worked as the Project

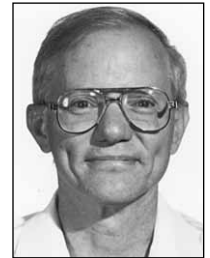
Manager of Natural Fibre Composites with the Swedish Institute of Composites in Piteå, Sweden.

Tim A. Osswald
Professor and Director
Polymer Engineering Center
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Dr. Tim Osswald is a Professor and Director of the Polymer Engineering Center at the University of Wisconsin, Madison, Wisconsin. Dr. Osswald's areas of research interest are in the fields of polymer processing and rheology. This includes modeling and simulation of processes such as injection, compression, resin transfer molding, and the forming process of advanced composites. He is currently working on the thermo-mechanical behavior of composites and the inertia effects during reaction injection mold filling. In addition, he is studying the forming process of fiber-reinforced sheet materials. From 1987 through 1989, Dr. Osswald was an Alexander von Humboldt Fellow at the Institute for Plastics Processing at the Technical University of Aachen in Germany. His research there involved modeling and simulating compression and injection molding, as well as a study of the rheology of fiber-reinforced polymer resins. Dr. Osswald teaches an introductory course in polymer processing and a graduate course in computational polymer processing. He received a B.S. and M.S. from South Dakota School of Mines and Technology, and a Ph.D. from the University of Illinois.

Roger M. Rowell
Project Leader
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Dr. Roger Rowell is a Research Chemist and Project Leader at the USDA Forest Products Laboratory in Madison, Wisconsin. He is also a Professor in the Department of Forestry, the Department of Biological Systems Engineering, and the Engineering Research Center for Plasma-Aided Manufacturing at the University of Wisconsin-Madison. His research interests include carbohydrate synthesis, chemical modification of lignocellulosics for property enhanced composites, materials science of natural fibers, composites from sustainable agro-resources, cold plasma modification of carbohydrate polymers, and fiber/thermoplastic composites. Previously, he was a United Nations Development Project Mission Leader for composites in India; Guest Scholar at Kyoto University; Guest Research Fellow at Forest Research; Guest Professor at the University College of North Wales; a National Science Foundation Exchange Professor at the Wood Research Institute, Kyoto University; and a Guest Professor at Beijing Forestry University. He received a B.S. in Chemistry/Math from Southwestern College, and an M.S. and Ph.D. in Biochemistry from Purdue University. He is the author of over 300 publications, has edited 9 books, and holds 22 patents.

Anand R. Sanadi
Consultant
Madison, Wisconsin, USA



Dr. Anand Sanadi has worked in research in the area of natural fiber composites for over 10 years, and research in composites for over 15 years. He has been working as a Consultant, on and off, for several

years, and recently worked for Teel-Global Resource Technologies. He is the chief inventor of the process to produce highly filled natural fiber composites, where fiber loadings of over 80% by weight is possible. His interests include structure-property relationships in polymers and composites, and adhesion and interfaces in non-similar materials. Previously, he was an Assistant Scientist in the Department of Biological Systems Engineering at the University of Wisconsin-Madison. He received a Bachelor in Textile Technology from the Indian Institute of Technology, an M.S. in Chemical Engineering from the University of Toronto, and a Ph.D. in Engineering Science from Washington State University.

Nicole M. Stark
Chemical Engineer
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USDA Forest Service
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Dr. Nicole Stark is a researcher in the Performance-Engineered Composites Group at the USDA Forest Products Laboratory (FPL) in Madison, Wisconsin. To help address FPL's mission to improve utilization of the wood resource, Nicole has been involved with the research and development of natural fiber/thermoplastic composites for over 10 years. Her research focus has been to examine the influence of raw materials and additives on composite performance. She is currently working towards a fundamental understanding of the changes that occur during weathering, including the development of methods for providing increased durability and procedures to use accelerated weathering tests to predict service life performance. She received a B.S. in Chemical Engineering and an M.S. in Mechanical Engineering from the University of Wisconsin, and a Ph.D. in Forest Science from Michigan Technological University.

Jerrold E. Winandy
Project Leader
USDA Forest Service
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Dr. Jerrold Winandy is the Principle Wood Scientist and Project Leader of the Performance-Engineered Composites Group at the USDA Forest Products Laboratory in Madison, Wisconsin. The group is responsible for developing new and improved composites from wood and other non-wood fiber sources using thermoset, thermoplastic, inorganic, and other naturally-derived binders. He is also an Adjunct Professor in the Department of Wood and Paper Science at the University of Minnesota. He received a B.S. and M.S. from Purdue University, and a Ph.D. from Oregon State University.

Session Speakers & Poster Presenters

Mirta I. Aranguren
Professor
INTEMA - Facultad de Ingenieria
Universidad Nacional de Mar del Plata
Mar del Plata, Argentina

Dr. Mirta Aranguren is a Professor in the Department of Chemical Engineering, National University of Mar del Plata (UNMdP) and a Senior Researcher of the National Research Council (CONICET). She holds a Ph.D. in Chemical Engineering from the University of Minnesota and has taught undergraduate and graduate courses at the UNMdP since then. Previously, she was Vice Head of the Department of Chemical Engineering at UNMdP and Vice Director of the Institute

of Research on Materials Science and Technology (INTEMA). She has also been an advisor of many doctorate and master students in the Materials Science Program at UNMdP. Dr. Aranguren has published 44 scientific papers in recognized international journals and five chapters as contributions of different internationally distributed books. She has served as reviewer of numerous well-known journals, such as *Journal of Rheology*, *Journal of Colloid and Interface Science*, *Journal of Applied Polymer Science*, *Macromolecular Materials and Engineering*, *Structural Engineering Mechanics*, *Materials Chemistry and Physics*, *Polymer and Polymer Composites*. Dr. Aranguren has received international grants from The Third World Academy of Sciences (TWAS, based in Italy) and the International Foundation for Sciences (IFS, based in Stockholm, Sweden). Her research on natural polymer composites received the IFS/King Baudouin Award (international award given by IFS, Sweden) to excellence in research (1996).

Dilpreet S. Bajwa
Director of Research & Development
EPOCH Composite Products, Inc.
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Dr. Dilpreet Bajwa is the Director of Research and Development for EPOCH Composite Products, Inc. in Lamar, Missouri. He is involved with new product development, product performance, and quality assurance of their composite product line. Prior to joining EPOCH, he worked with International Paper Company as Senior Product Development Engineer at their Corporate Research Center in Loveland, Ohio. Later, he worked as a Research Scientist for Masonite International Corporation at Coates Technical Center in Chicago, Illinois. He graduated from the University of Illinois in 2000 with a Ph.D. in Wood Science and Engineering. His research experience involved product development, analysis, and testing of wood and natural fiber-plastic composites. He has published several peer reviewed papers and articles on wood-plastic composites.

Shelly A. Barnhart
Plastic Applications Chemist
Dover Chemical Corporation
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Shelly Barnhart is a Plastic Applications Chemist for Dover Chemical Corporation in Dover, Ohio. She is responsible for polyolefin extrusions - additive evaluations; physical and mechanical testing; flame retardant formulation and testing; PVC stabilizer evaluations; and all wood-plastic composite additives and evaluations. She received an A.S. in General Science, an Associate of Applied Science Plastics Technology, and a B.S. in Plastic Manufacturing Engineering Technology from Kent University.

Magnus Bengtsson
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Magnus Bengtsson is a Ph.D. Student in the Department of Engineering Design and Materials at the Norwegian University of Science and Technology in Trondheim, Norway. He received a B.S. and M.S. in Chemical Engineering from Chalmers University of Technology.

Lars Elof Bryne
Ph.D. Student
KTH Building Materials
Royal Institute of Technology
Stockholm, Sweden

Lars Elof Bryne is a Ph.D. Student at KTH Building Materials, Royal Institute of Technology, Stockholm, Sweden. Previously, he was an Assistant Engineer R&D, Materials Technology at Habia Cable AB. He received an M.S. in Materials Technology from the Royal Institute of Technology (KTH).

Urs Buehlmann
Assistant Professor and Extension Specialist
Department of Wood & Paper Science
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Raleigh, North Carolina, USA

Dr. Urs Buehlmann received a Ph.D. in Wood Science and Forest Products and an M.B.A. in Finance and Management from Virginia Tech. He previously obtained an Engineering degree from the Swiss Institute of Wood Technology. Since 2000, he has been an Assistant Professor and Extension Specialist with the Department of Wood and Paper Science at North Carolina State University (NCSU) in Raleigh, North Carolina. Dr. Buehlmann worked for over 10 years in industry in Europe and the United States. Over the past 4 years with NCSU, Dr. Buehlmann has been responsible for studies on the impacts and opportunities of globalization and technological change on the wood products industries, has solved manufacturing optimization problems, and has worked on issues relating to the recycling of wood products. He also teaches courses in wood products manufacturing and business.

Gilber Ramirez Calderon
Department of Wood, Cellulose & Paper
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Gilber Ramirez Calderon was born in Lima, Peru in 1971. He studied Forestry Engineering at the Agricultural University La Molina in Lima 1992-1997. From 1998 -2000, he was involved in research on palm wood at the National Institute of Agricultural Research at La Molina University and worked with the wood and furniture industry in 2001. He studied for his M.S. degree at the University of Guadalajara, Mexico from 2002-2004. As part of his master's studies, Mr. Calderon spent a 6 month assistantship at the USDA Forest Products Laboratory engaged in research on fiber/plastic composites, with particular emphasis on agave fibers.

Richard J. Clark
Senior Market Development Manager
Luzenac America, Inc.
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Richard Clark graduated from Pennsylvania State University with a B.S. in Chemistry and M.S. in Polymer Science. He is currently the Senior Market Development Manager for Luzenac's worldwide plastics business. During his career in polymers, he has worked with polyolefins and polyesters in areas ranging from synthesis, blends and alloys, and adhesion development. He has written over 40 technical publications covering plastic applications and is the holder of 17 patents.

Carlos A. Correa
Associate Professor
Postgraduate Program in Materials
Engineering & Science
Universidade São Francisco
Itatiba, São Paulo, Brazil

Dr. Carlos Correa is an Associate Professor in the Postgraduate Program in Materials Engineering and Science at the Universidade São Francisco, Itatiba, Sao Paulo, Brazil. Previously, he was a Research Assistant, A.W. Faber Castell S.A.; Laboratory Manager, Materials Characterization Centre; Research Assistant, Universidade do Minho; Ph.D. Student, Cranfield University; and Research Assistant, Nitriflex Petrochemical S.A. He received a Bachelors in Materials Engineering and an M.S. from the Federal University of São Carlos, and a Ph.D. in Advanced Materials from Cranfield University.

David M. Dean
Senior Research Engineer
DuPont Packaging & Industrial Polymers
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Dr. David Dean is a Senior Research Engineer at DuPont Packaging and Industrial Polymers in Wilmington, Delaware. Currently, he is a member of the Application Development Group within DuPont Packaging and Industrial Polymers and is involved in projects focused on functionalized ethylene copolymers and reactive extrusion. He has been with DuPont for the past 7 years; his first 5 years were in polymer research and development at the DuPont Experimental Station. He received a B.S. in Chemical Engineering from Virginia Tech, and an M.S. and Ph.D. in Chemical Engineering from Princeton University.

Alex Dragomirescu
R&D Manager
Wellington Polymer Technology Inc.
Chatham, Ontario, Canada

Alex Dragomirescu is the Research and Development Manager at Wellington Polymer Technology Inc. in Chatham, Ontario, Canada. He is experienced in working with and researched natural fiber-thermo-plastic composite materials; has a comprehensive understanding of formula components and possible interactions with priority for coupling agents and compatibilization mechanism; provided input for improvement of composite formulation and testing laboratory methods; initiated the set up of new research and development laboratory, including development of several specific testing methods and equipment; created a data base for raw materials and plastics additives; involved in multiple projects for new products development and has interests in composites simulation; extensive studies and experiments regarding weathering effects on composite materials; assessed budget requirements for research and development activity and performed cost analysis for possible new products; and developed new testing procedures that made the analysis process more time- and cost-effective. He received a B.S. in Chemical Engineering from the University Petroleum-Gas of Ploiesti, and an M.S. in Chemical Engineering from the University of Western Ontario.

Matthew Dura
Graduate Research Assistant
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Orono, Maine, USA

Matthew Dura is a Graduate Research Assistant in the Department of Civil and Environmental Engineering, University of Maine, Orono, Maine. He is a Master's Candidate in Civil Engineering, specializing in structures. Previously, he was a Design Engineer at Sheppard Engineering, and a Contract Engineer at General Motors. He received a B.S. in Civil Engineering from Michigan Technological University.

Kurt Erlacher
Application Scientist
Bruker-AXS Inc.
Madison, Wisconsin, USA

Dr. Kurt Erlacher is an Application Scientist at Bruker-AXS Inc. in Madison, Wisconsin. His responsibilities include Small Angle X-ray Scattering (SAXS) in North America. Previously, he was a Post-Doctorate at the University of Aarhus; Scientist at the Material Center Leoben GmbH; and conducted research at the Institut Charles Sadron. He is the author or coauthor of numerous publications. He received a degree in Applied Physics from the University of Technology, Graz; and a Ph.D. in Materials Sciences from the University of Leoben.

James S. Fabiyi
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Moscow, Idaho, USA

James Fabiyi is a Ph.D. Student and Graduate Research Assistant in the Department of Forest Products, University of Idaho, Moscow, Idaho. His responsibilities include conducting research on chemistry of wood-plastic composites using different instruments such as FTIR, Pyrolysis GC-MS, DSC, Colorimeter, etc. Previously, he was an Assistant Lecturer at the Federal University of Technology, Akure, Nigeria. He received B.Tech. and M.Tech. degrees from the Federal University of Technology.

Angelo G. Facca
Ph.D. Candidate
Department of Chemical Engineering
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University of Toronto
Toronto, Ontario, Canada

Angelo Facca obtained his B.S. degree in Chemical Engineering from Lakehead University (Thunder Bay, Ontario) in 2000. In 2003, he completed his M.S. in Control Engineering from Lakehead University under the supervision of Dr. A. Gilbert and Dr. K. Natarajan. His thesis was titled "Modelling and Control of Various Styles of Paper Machine Headboxes." Mr. Facca is currently a Ph.D. Candidate in the Department of Chemical Engineering and Applied Chemistry at the University of Toronto working under the supervision of Dr. Mark Kortschot and Dr. Ning Yan. His Ph.D. research activities involve predicting the mechanical properties of natural fiber-reinforced thermoplastics.

F. Louis Floyd
Consultant
Independence, Ohio, USA

Louis Floyd has over 37 years of research and development service to the coatings industry. After concluding his undergraduate studies in Chemistry at the University of Kansas in 1967, he joined the Rohm and Haas Company at their Spring House Research Center, where he spent 5 years conducting research on emulsion polymers for coatings applications. He then moved to Glidden (now ICI Paints), where he spent 21 years at their Strongsville Research Center leading various research programs on new coatings systems for the architectural, industrial OEM, and industrial maintenance markets. Next he served 5 years with Duron, Inc., as their Vice President of Technology, followed by 6 years with PRA Laboratories, Inc., as their Executive Director. In 2004, he retired and became active as a consultant to the coatings industry. During his career, Mr. Floyd has been active in five professional organizations (ACS, FSCT, SSPC, NACE, SPE), has published and presented papers both domestically and internationally, and has been a lecturer at Lehigh, Kent State, and North Dakota State Universities in their respective short course programs on coatings. He has been active in the Philadelphia, Cleveland, Baltimore, and Detroit coatings societies of the FSCT. For over 20 years, he has been a reviewer for the *Journal of Coatings Technology*, including the new *JCT Coatings Tech* and *JCT Research*. He has served on the FSCT Board of Directors, and is currently serving as a Trustee of the Coatings Industry Education Foundation, and as a member of the Mattiello Award Committee. He is a Past Chair of the Gordon Research Conference on the Physics and Chemistry of Coatings and Films. He holds four Roon awards, the Technical Focus award, and the Mattiello award from the FSCT; and received the President's award for technical excellence from Glidden.

Francisco J. Fuentes T.
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Francisco Fuentes is an Associate Professor of Wood Science and Technology in the Department of Wood, Cellulose & Paper, Universidad de Guadalajara, Zapopan, Jalisco, México. His responsibilities include teaching and research on physical and mechanical wood properties and particleboard manufacturing. He received an M.S. in Wood, Cellulose, and Paper Science from Universidad de Guadalajara.

William Gacitua E.
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William Gacitua is a Graduate Research Assistant in the Wood Materials and Engineering Laboratory at Washington State University (WSU), where he is working on a Ph.D. in Civil Engineering. His responsibilities at WSU include research in the field of wood-plastic composites. He is also an Assistant Professor at the Universidad del Bio-Bio, Chile. His responsibilities in the Department of Wood Science at the Universidad del Bio-Bio include teaching and research in wood composites and wood mechanics. He received a Master in Wood Science and Technology from the Universidad del Bio-Bio.

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

Marek Gnatowski
Technical Director
Polymer Engineering Co. Ltd.
Burnaby, British Columbia, Canada

Dr. Marek Gnatowski is Technical Director, Polymer Engineering Co. Ltd., Burnaby, British Columbia, Canada. He has 33 years of experience in industrial consulting, process control, and research and development; and 3 years of experience in teaching polymer chemistry and technology at University of Technology level. He is the author of three book chapters in *Plastics Waste Management* published by Marcel Dekker, 10 papers in scientific journals, 13 conference presentations, 11 patents, and more than 500 unpublished reports including nine

technical opinions on legal matters. He was nominated for the Canadian Manning Innovation Award (2002) by Weyerhaeuser and winner of the annual contest for the best technical project in Poland (Master of Technique, 1979). Previously, he was President/Technical Director, Polymer Engineering Company Ltd., Burnaby; Director of Polymer Chemistry, Industrial Science Laboratory Inc., Burnaby; Technician, Huntington Urethane Products Ltd., Richmond; Head of Polymer Research Group/Research Engineer, Institute of Meteorology and Water Management, Warsaw, Poland; Consultant, Chief Technical Organization, Warsaw, Poland; and Research Assistant Engineer, Warsaw University of Technology. He received an M.S. Eng. and Ph.D. from Warsaw University of Technology.

Warren J. Grigsby
Senior Scientist
Biomaterials Engineering Group
Forest Research
Rotorua, New Zealand

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

Masud S. Huda
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Composite Materials & Structures Center
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Dr. Masud Huda is a Visiting Research Associate in the Composite Materials and Structures Center at Michigan State University, East Lansing, Michigan. His responsibilities include research for the development of environmentally friendly industrial polymer composites by conducting research on fiber-reinforced composite materials. Dr. Huda's primary research is focused on biocomposite materials, biodegradable polymers, materials applications in packaging, and new biobased materials development. He received a B.S. from Dhaka University, and an M.S. and Ph.D. from Shinshu University.

Byungsun Hwang
Director, Materials Processing
Composite Materials Group
Korea Institute of Machinery & Materials
Changwon, South Korea

Dr. Byungsun Hwang is Director of Materials Processing, Composite Materials Group, Korea Institute of Machinery and Materials (KIMM), Changwon, South Korea. He is responsible for planning and evaluation of projects, which cover composite materials, high temperature materials, high strength materials, and metal working and plasticity. Previously, he was Group Leader of Composite Materials Group, KIMM; Senior Researcher, KIMM; Research Associate, University of Dayton Research Institute; Research Engineer, Agency for Defense Development, Korea. He received a B.S. from Pusan National University, and an M.S. and Ph.D. from the University of Dayton.

Haihong Jiang
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Haihong Jiang is a Ph.D. Candidate in the Department of Forestry at Michigan State University, East Lansing, Michigan. Her area of expertise is PVC/Cu-treated woodfiber composites.

Roberts Joffe
Associate Professor
Division of Polymer Engineering
Luleå University of Technology
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Dr. Roberts Joffe is an Associate Professor in the Division of Polymer Engineering at Luleå University of Technology, Luleå, Sweden. His responsibilities include undergraduate teaching in courses on properties, applications and manufacturing of polymers and composites. He is also involved in supervising of Master Thesis and Ph.D. students at the division. Dr. Joffe is involved in miscellaneous research projects, mostly EU funded projects, in which Luleå University is a partner. His main areas of research are natural fibers and their composites, non-crimp fabric composites, and carbon nanotube-reinforced polymers. His research work is ranging from experimental investigations (manufacturing, testing) to modeling (analytical and numerical) of properties and performance of composite materials on different size scales. He received an M.S. in Continuum Mechanics from the University of Latvia, and a Ph.D. from Luleå University of Technology.

Melissa Kahl
Graduate Student
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Melissa Kahl is a Graduate Student in the Structural Engineering and Mechanics Program, Department of Civil & Environmental Engineering, University of Maine, Orono, Maine. The Program offers graduate courses and opportunities for advanced research in several areas of modern structural mechanics and design. She received a B.S. from Syracuse University in Maine.

Hans Korte
President
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Dr. Hans Korte is President of the engineering and consultant company "Innovationsberatung Holz & Fasern" located in Wismar, Germany. Dr. Korte is involved with engineering research and developments in the field of wood and fibers. His company specializes in leading edge solutions for the development, introduction, and marketing of new products and/or procedures. Dr. Korte undertakes developmental activities for his clients to provide an early insight into areas such as copyright prior to full product development and marketing. His company researches potential funding opportunities and identifies a range of solutions that will assist clients with the wider development and sales of their products. Professional project management ensures that deadlines and targets are achieved to budget. Additional partners can be factored into solutions such as Universities and if appropriate other businesses. Dr. Korte's clients can benefit from constant review of projects and milestone checks to ensure satisfactory progress and adjustments to deadlines where necessary. Typical areas of activity include the development of impregnation processes for solid wood; quality improvement measures to planed products; development of woodfiber insulating materials and the corresponding production processes; wood-plastic composite; improving the ply bond strength of timber; recycling of high-performance fibers from composite materials; structural mats; fire protection medium; and development of special plastics. Previously, he was President of Akzo Nobel Geosynthetics GmbH in Wuppertal, Germany. He received a Diploma-Holzswirt (comparable to wood science and technology) and a Ph.D. from the University of Hamburg.

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Dr. Timothy Rials is a Professor and Director of the Forest Products Center, University of Tennessee, Knoxville, Tennessee. His research interests include structure and properties of wood/polymer interfaces, raw material assessment and process monitoring using spectroscopy, and cure analysis of thermosetting polymers. He is the author or coauthor of numerous publications. He received a B.S. in Forestry and Forest Biology from Mississippi State University, and an M.S. and Ph.D. in Wood Science and Technology from Virginia Tech in 1983 and 1986, respectively. He became an Assistant Professor in the Forest Products Laboratory at University of California in 1986; joined the USDA Forest Service, Southern Research Station as a Research Physical Scientist in 1988 and was promoted to Project Leader/Research Scientist in 1996; he then joined the Department of Forestry, Wildlife and Fisheries at the University of Tennessee, and became the Director of Tennessee Forest Products Center in 2001.

Christopher D. Risbrudt
Director
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Since being named Director of the USDA Forest Service's Forest Products Laboratory (FPL) in September, 2001, Dr. Christopher Risbrudt has focused the laboratory's attention on forest health and the wise use of wood and wood products. FPL has concentrated on three broad areas: 1) Developing new uses for small-diameter and underutilized forest materials; 2) Extending the useful life of wood products; and 3) Facilitating the recycling of wood and paper products. To ensure the maximum benefit from FPL's research, Dr. Risbrudt also has encouraged increased communications and technology-transfer activities. He also has worked to ensure that FPL, the nation's leading wood-research institution since 1910, has the facilities, organizational structure, and technical and human resources necessary to continue its world-class research into wood and wood products. In 2004, Dr. Risbrudt's efforts and achievement were recognized by the Federal Laboratory Consortium for Technology Transfer (FLC), representing federal laboratories and research centers, when they named him Laboratory Director of the Year. Dr. Risbrudt brought to the task a background in planning and management both in the Forest Service headquarters in Washington, D.C. and in the field. He also was familiar with FPL, having begun his Forest Service career as a Research Forester there in 1978. In 1980, he was assigned to the Forest Service's Washington, D.C. office as an Economist with State and Private Forestry staff. He then served as a Research Project Leader at the North Central Forest Experiment Station in St. Paul, Minnesota from 1983 to 1985, when he returned to Washington as Director of Policy Analysis. He later was named Deputy Regional Forester for the

Forest Service's Northern Region, headquartered in Missoula, Montana. He returned to Washington as Director of Ecosystem Management in 1995. He was named Director of Strategic Planning and Resource Assessment in 2001, and later that year, Acting Deputy Chief, Programs and Legislation. He was also designated to assist the transition for the new administration. After graduation from the University of Minnesota in 1972, he served in the Peace Corps as a Forest Planner in Morocco. After returning to the U.S., he attended Michigan State University, where he earned a Master's degree in Forest Administration and a Ph.D. degree in Forest Economics.

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Dr. Mohini Sain is a Professional Engineer and holds a Ph.D. in Chemical Engineering. Before joining academia, he worked approximately 8 years in industry in various capacities including as a consultant in Asia, Europe, and the United States. Since 1997, he returned to academia and developed research programs in green composites, recycling, surface science of natural polymers, and more recently in coatings, in collaboration with more than 30 industry partners. He is involved in several Network Centre of Excellence programs and serves as Group Leader of Natural Fiber Composites for the Canadian Network Center of Excellence for Automotives of the 21st Century and collaborates internationally in the paper and natural composites field. In 2001, he received the Prestigious Industry-University Synergy Award from the Conference Board of Canada and NSERC for his excellence to transform research innovation into industrial practice. He is the author of 170+ technical publications in international journals and conferences and holds patents in paper recycling, composites, and fiber products. He is also the author of several book chapters. Dr. Sain is a member of several diverse organizations including CPI, TAPPI, PAPTAC, MMO, and the Ontario Professional Engineer Association. He is also a member of advisory boards of industry and institutions.

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Michael Schmitz is a Graduate Student at RWTH Aachen University in Aachen, Germany. He is currently working on his Diploma thesis on the subject "Examination of the Validity of Common Mixing Rules for Natural Fiber-Reinforced Biopolymers." The experiments were made at the USDA Forest Products Laboratory and the Polymer Engineering Center at the University of Wisconsin in Madison, Wisconsin, and the FIBRE Institut in Bremen, Germany.

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Vera Steckel is a Student of Wood Science and Technology, presently working on her Diploma thesis at the Institute of Wood Physics and Mechanical Technology of Wood, Department of Wood Science, University of Hamburg, Hamburg, Germany. The objective of her Diploma thesis is to investigate the effects of material parameters on the diffusion and sorption properties of polypropylene-wood flour composites.

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Dr. Siqun Wang is an Assistant Professor in the Forest Products Center at the University of Tennessee, Knoxville, Tennessee. He is also a Professor at Nanjing Forestry University (China) and a Professor at Southwest Forestry College (China). Previously, he was an Associate Professor, Lecturer, and Assistant Lecturer at Nanjing Forestry University; a Post-Doctoral Research Associate at the University of Nancy 1; and a Post-Doctoral Research Associate at the University of Tennessee. He is a member of the American Adhesion Society; member of the Forest Products Society, where he serves as Vice Chair of the Structural Panels Group (2003-present) and served as Trustee of the Mid-South Section (2000-2003); and member of the Society of Wood Science and Technology. He is the author or coauthor of numerous publications and holds one U.S. patent. He received a B.S., M.S., and Ph.D. in Wood Science and Technology from Nanjing Forestry University.

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Dr. Joe Williams is Global Technical Service Team Leader at Lonza Inc. in Williamsport, Pennsylvania. His responsibilities include: conduct research and development projects in areas of polymer and powder metal lubricants; and provide technical information to sales, marketing, and customers. Previously, he was R&D Manager at Bird and Laboratory Manager at General Electric. He received a B.S. in Chemistry and Mathematics from the University of Wyoming, and a Ph.D. in Physical-Organic Chemistry from the University of Florida. He is a Fellow of the Society of Plastics Engineers.

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ABSTRACTS

MONDAY MORNING, MAY 23

OPENING PLENARY SESSION

WPCs: Putting Innovation on a Faster Track

Louis M. Rossi and *James Morton*, Senior Partners, Principia Partners, Exton, Pennsylvania, USA

Wood-plastic composite (WPC) producers are increasingly recognizing the importance of new products to meet their sales and earnings objectives. However, custom tailoring of WPC compounds to meet the wide variety of customer requirements results in a proliferation of new products and must be managed carefully. While an efficient new product development (NPD) process is the key to market expansion, revenue growth, and improved profitability, the desired results are only achieved when direct customer input on the market need is employed. Successful composite products companies drive NPD by integrating this process with the rest of the business organization. This presentation will begin with a review of key developments in wood-plastic composites, a highly dynamic and changing industry. The key market drivers for WPCs will be identified to show what challenges and opportunities loom ahead, and the leading innovators in these composite products and their NPD practices will be examined to provide examples of how to marry market need with product innovation. Finally, the value of an effective NPD process to suppliers, processors, and the ultimate end user will be explored.

N-FibreBase, Information Portal for Natural Fiber-Reinforced Polymers and Bio-polymers

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Natural fibers such as flax and hemp are used increasingly for the reinforcement of materials. In some cases they already replace the classical reinforcement fibers such as glass. However, the existing components are restricted to applications with low loads. Up to now, higher-loaded structural components have not been made from natural fiber-reinforced materials. This is due to the fact that specific properties, which are required for dimensioning, are not available at the necessary quality level. Therefore, to stand up against established materials, natural fiber-reinforced products must become calculable, i.e., it has to be proved that common design methods are applicable to natural fiber-reinforced materials. Also, relevant material properties must be available. For this purpose, the N-FibreBase internet portal has been developed, which makes all required information available. The N-FibreBase system is based on the project "Data-base with Characteristic Values for Construction and Design of Parts made from Natural Fiber-Reinforced Polymers", funded by the German ministry of agriculture. Four project partners set up a modular database system. Besides characteristic values of natural fibers, it provides natural fiber-reinforced polymers and biopolymers, information about suppliers, prices for natural fibers, and application examples. The platform is completed by up-to-date literature references and broad background information about fiber and compound life cycle and processing. However, in addition to the importance of the availability of characteristic values, the quality of the material parameters significantly determines the quality of simulations and of every other design task. N-FibreBase closely follows the well-known plastics database CAMPUS, which was established by resin suppliers, in order to provide the market with comparable material data. Without exceptions, N-FibreBase consists of properties that have been measured by strictly standardized procedures. Thus, they are comparable. This principle applies to fibers, semi finished products (non-wovens), as well as compounds (e.g. for injection molding). The system is free of charge and available in English, German, and French at <http://www.N-FibreBase.net>. N-FibreBase has become a well accepted information platform for the European industry. Most likely it will help to increase the use of natural fibers in different industrial sectors.

Influence of Class Action Lawsuits on Service Life Prediction Programs

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For over a century, the coatings industry has conducted research on the weatherability of coatings and coated articles, with the goal of being able to predict that weatherability by some means of (accelerated) laboratory testing. In spite of the considerable effort expended, such efforts have been largely unsuccessful. Meanwhile some other industries' very existence has depended on achieving sound service life prediction (e.g. commercial air travel, medical devices, electronics) because broad-based commercial acceptance would not be possible without it. One possibility for the lack of success in the coatings industry may well be that there is no corresponding overarching compulsion to achieve such success sufficient to drive the expenditure of the required resources. It is the thesis of this presentation that class action product liability lawsuits may well provide the needed impetus. A review of case studies of recent class action lawsuits demonstrates that manufacturers need to better understand such issues as the sources of liability, limitations of current test protocols, role of installation errors and lack of product robustness, and the misuse of warranties to avoid operating from an indefensible legal prediction. It is suggested that such considerations can have a significant impact on present and future service life prediction programs.

MONDAY AFTERNOON, MAY 23

CONCURRENT SESSIONS

SESSION 1A: MATERIALS AND PROCESSING

Effects of Woodfiber Grade on Fine-Celled Foaming of Plastic/Woodfiber Composites

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Foaming of plastic/woodfiber composites (PWC) with a fine-celled structure can offer benefits such as improved ductility and impact strength, lowered material cost, and lowered weight, which can enhance their utility in many applications. This presentation investigates the effects of woodfiber grade on fine-celled extrusion foaming of plastic/woodfiber composites in terms of cell density, cell size, and expansion ratio. The effects of woodfiber grade on the viscosity of PWC are also investigated. This study can establish guidelines for the selection of woodfiber grades for PWC foams, as well as for optimal processing conditions to achieve desired properties.

Cellulose-Based Fibers and Their Polymer Composites: Characterization and Prediction of Properties

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Natural fibers are increasingly being used as reinforcement of polymer matrix composites. The application of natural fibers is motivated by a combination of environmental friendliness and economical feasibility, natural occurrence, renewability of fiber resources, and biodegradability. Cellulose-based natural fibers, such as wood and flax fibers for instance, possess acceptable absolute strength and stiffness values in the fiber direction. As a matter of fact, the best cellulose-based fibers can compete and even outperform glass fibers in terms of mechanical properties. Yet, currently the use of natural fibers as reinforcement in technical applications occur mainly in the automobile and packaging industries in parts where high load-carrying capability is not required.

However, there is great potential for natural fiber composites to be used in structural applications, since the quality of the fibers themselves and composites based on these fibers have sufficiently improved in recent years. One of the major drawbacks of natural fibers is the large variability in properties due to fiber damage during the manufacturing process. Furthermore, fiber properties can change from batch to batch (depending on the time and place of harvest). The most affected fiber property is strength, which can vary greatly due to introduced defects because of the specifics of the manufacturing process. Thus, in order to use natural fibers to design load-bearing structures, one needs tools to assure the quality of raw materials and to predict the properties of the final product. The main objective of this investigation was to develop tools which can be easily applied to characterize natural fibers and to evaluate the properties of randomly-oriented natural fiber polymer composites. In this study cellulose-based reinforcement (flax fibers) were tested by different techniques traditionally used to characterize synthetic fibers (single fiber fragmentation and single fiber tests). The single fiber fragmentation test was modified in order to adapt for particular requirements of the natural material (e.g., the length of the fibers is often limited). Results of these tests were verified by similar experiments performed on glass fibers and by other independent tests on flax fibers. Obtained values for strength and stiffness of fibers were used to predict properties of randomly-oriented polymer composites and these predictions were compared with experimental results. This study shows that modified single fiber fragmentation test can be used as a quality control tool to characterize flax fibers and also can be potentially applied to any type of natural fibers. Simple strength and stiffness prediction models for flax fiber-reinforced polymer composites produce results that correlate very well with experimental data.

Effect of Impact Modification on the Foamability of Woodfiber-Plastic Composites

Laurent M. Matuana, Assistant Professor, Department of Forestry, Michigan State University, East Lansing, Michigan, USA

Wood-plastic composites (WPCs) need various additives for processing, surface appearance, strength properties, durability, etc. Although these additives are critical to performance, some may affect processing, particularly during foaming. Solid state microcellular foaming technology was employed to investigate the influence of impact modification on the foamability of WPCs. Particular emphasis was placed on examining the effects of impact modifier types (crosslinked versus uncrosslinked) and concentrations on the sorption behavior of CO₂ in the samples and volume expansion ratio of foamed samples. The rate of gas diffusion in uncrosslinked-modified samples was much higher than in the crosslinked counterparts due to the greater softening effect of uncrosslinked modifier. The experimental results indicated that impact modification accelerates the rate of gas loss during foaming process, which impedes the growth of nucleated cells, independent of modifier type. Due to this accelerated gas loss, impact modification inhibits the potential of producing foamed samples with volume expansions similar to those achieved in unmodified samples. Consequently, choice of impact modifiers is critical for the foamability of WPCs.

Influence of Woodfiber-Plastic Material Composition on Machining and Abrasion Performance

Urs Buehlmann, Assistant Professor and Extension Specialist, Department of Wood & Paper Science, and *Daniel Saloni*, Research Associate, and *Richard L. Lemaster*, Director, Wood Machining & Tooling Program, Department of Wood & Paper Science, North Carolina State University, Raleigh, North Carolina, USA; and *Michael P. Wolcott*, Professor and Research Director, Wood Materials & Engineering Laboratory, Washington State University, Pullman, Washington, USA

The U.S. construction market is a large user of woodfiber-plastic composite materials, especially for decking materials. These materials may need to be machined prior to being ready for use and they need to have certain mechanical characteristics when in use. One of the most important mechanical factors for any decking material is its resistance against surface wear, such as wear caused by human traffic. This study, a collaboration between North Carolina State University's Wood Machining and Tooling Research Program and Washington State University's Wood Materials and Engineering Laboratory, was performed to evaluate the impact of different woodfiber-plastic material compositions on machinability and abrasion resistance. Varying amounts of wood, HDPE, talc, and zinc borate were used in the production of test samples. Comparisons were also made with solid wood

and pure plastic decking materials. Also, the surface roughness of all materials was monitored during the experiments. Thus, this research allows producers of woodfiber-plastic composite materials to correlate the material composition to machining and abrasion performance.

WPC Made with Different Processes: A Comparative Investigation

Hans Korte, President, Innovationsberatung Holz & Fasern, Wismar, Germany; and *Harald Hansmann*, Professor, Institut für Polymertechnologien e.V., Wismar, Germany

Wood-plastic composites (WPC) are produced in a variety of different processes. There are one-step and two-step processes. The best known one-step process in Europe is the extrusion of profiles by using a conical counter rotating twin-screw extruder feeding woodfibers, thermoplastic granules, and additives into the hopper of the extruder. Besides the one-step process there are several possibilities to produce compounds of woodfibers and plastics for the profile - extrusion in one or twin-screw extruders. In our investigation, we compared two different hot and cold mixing processes, two different twin-screw compounding processes, and different operating schemes to produce WPC granules or pellets. The woodfiber varied in content between 65% (w/w) and 80% (w/w) as well as in particle size. A high and a low MFR polypropylene was used as a matrix polymer. WPC-samples for testing were made by extrusion with a single-screw extruder or by pressing with a hot press and were characterized by the shape of the surface, density, water absorption, strength, and flexural modulus (elasticity).

SESSION 1B: NEW MATRICES

Mechanical, Thermal, and Morphological Studies of Poly(lactic acid) PLA/Talc/Recycled Newspaper Fiber Hybrid 'Green' Composites

Masud S. Huda, Visiting Research Associate, Composite Materials & Structures Center, *Amar K. Mohanty*, Associate Professor, School of Packaging, and *Lawrence T. Drzal*, University Distinguished Professor and Director, Composite Materials & Structures Center, Michigan State University, East Lansing, Michigan, USA; *Kelly Williams*, Research Engineer, Plastics Research, and *Deborah F. Mielewski*, Technical Expert, Team Leader of Plastics Research, Materials Research & Advanced Engineering Department, Scientific Research Laboratory, Ford Motor Company, Dearborn, Michigan, USA; and *Manju Misra*, Associate Research Professor, Composite Materials & Structures Center, Michigan State University, East Lansing, Michigan, USA

'Green' composites are successfully fabricated through extrusion followed by injection molding from recycled newspaper fibers/talc and polylactic acid (PLA). According to a U.S. Environmental Protection Agency (EPA) report, paper/paper products constitute the largest component of municipal solid waste (MSW). The biopolymer PLA has recently been highlighted because of its origin from corn. Talc is also a natural product. The recycled newspaper and talc hybrid reinforcements of the PLA polymer matrix has been targeted in the design and engineering of 'green' composites with balanced properties and added advantages of cost benefits plus the eco-friendliness of all the components in the composites. In this study, the mechanical and thermo-mechanical properties of the hybrid composites were investigated and compared with those of composites from either of the reinforcements. The tensile, flexural, and impact strength of these hybrid composites was found to be significantly higher than those made from either PLA/recycled newspaper fiber or PLA/talc. The flexural properties of PLA/newspaper based composites improved significantly with the addition of 10% talc. The hybrid green composites resulted in quite encouraging properties with a flexural strength value of 94 MPa and flexural modulus of 10.8 GPa, while unhybridized PLA/recycled newspaper fiber based 'green' composites exhibited flexural strength and modulus values of only 77 MPa and 6.7 GPa, respectively. Recycled newspaper fiber and talc-reinforced polypropylene (PP) hybrid composites were also made in the same way as the PLA composites for comparison. The 'green' composites showed much improved properties as compared to PP-based counterparts.

Modeling the Mechanical Properties of Natural Fiber-Reinforced Biopolymers

Michael Schmitz, Graduate Student, RWTH Aachen University, Aachen, Germany; *Tim A. Osswald*, Professor and Director, Polymer Engineering Center, University of Wisconsin, Madison, Wisconsin, USA; and *Daniel F. Caulfield*, Research Chemist, USDA Forest Products Laboratory, Madison, Wisconsin, USA

The use of mechanical and process simulation programs is common in the composite design process. Considering the anisotropic properties of reinforced materials, the properties of these materials have to be calculated from the fiber and matrix properties. This can be done by mixing rules. This presentation demonstrates the applicability of commonly used micromechanics models (Halpin-Tsai and Tandon-Weng) which predict the elastic properties of unidirectional short fiber composites. In our experiments, four different fibers (kenaf, flax, jute, and coir) were blended with PLA in a thermokinetic mixer, dried and then injection molded, with the fiber volume fractions varying between 20% and 50%. The specimens were tested for tensile properties. The influences of the different mixing-parameters were examined. To accomplish this, all material parameters requested by the mixing rules were measured. The elastic moduli of the fibers were determined according to <http://www.N-Fibre Base.net> test guidelines. Thus, from the highly scattered single values, reasonable average values, which can be inserted into the mixing rules, were determined. The exact fiber volume content of the compound was measured via densitometry. In order to measure the aspect ratio of the fibers, the matrix was dissolved. The comparison between the experimentally determined and the calculated material properties showed good accordance. All measured data are available at the N-FibreBase portal.

Reutilization of Polyolefin Float Rope from Lobster Fisheries into WPCs

Shane R. O'Neill, Wood Plastic Composite Specialist and Project Manager, Advanced Engineered Wood Composites Center, *Douglas J. Gardner*, Professor of Wood Science, Department of Forest Management and Advanced Engineered Wood Composites Center, and *Katherine L. Stephens*, Graduate Research Assistant, Advanced Engineered Wood Composites Center, University of Maine, Orono, Maine, USA

Currently, environmentalists, lobster fisherman, and federal agencies are embroiled in the issue of protecting the North American Right Whale in the Gulf of Maine. The federal government is working towards mandates removing polyolefin-based rope (commonly known as "poly" or "float" rope) used by the lobster industry to connect lobster traps together. The removal of this type of rope from the ocean would prevent whale entanglement from occurring. Once this mandate is in place, the National Marine Fisheries Service estimates that 5 million pounds of float rope will be removed from service in the Gulf of Maine. As part of this mandate, the federal government is working towards a buy-back program, to bring the float rope out of service, and to minimize offshore dumping. As part of this effort, the conversion of float rope into a usable raw material was examined. The conversion of this material was examined, involving the reduction, separation, cleaning, and pelletizing of the rope, as well as its properties in-use within WPCs. The presentation contains discussion of the processing operations, as well as empirical data for flexure, tension, and izod impact resistance.

Wetlay Manufacture of Cellulose Pulp Fiber-Reinforced Poly(trimethylene terephthalate)

Todd A. Bullions, Research Scientist, Center for High Performance Manufacturing, Virginia Tech, Blacksburg, Virginia, USA; and *Edward Schut*, Director of Marketing, CreaFill Fibers Corporation, Chestertown, Maryland, USA

Cellulose pulp fibers generally have aspect ratios ranging up to approximately 150 depending on their processing. Their high aspect ratios, along with their ribbon-like shape, provide large amounts of surface area for load transfer from matrix to fiber. Therefore, cellulose fibers act not just as fillers in polymer matrix composites, but as reinforcements. Cellulose fibers can increase the modulus, strength, and impact resistance of various polymers. Traditionally, cellulose fibers have been limited to reinforcing commodity thermoset resins and polyolefin thermoplastics due to the lower processing temperatures of these polymers. However, the pending commercialization of a partially bio-based version of poly(trimethylene terephthalate) (PTT) has generated interest in reinforcing this structural thermoplastic polyester with cellulose pulp fibers. This interest has been generated due to the melt

temperature of PTT allowing for processing with cellulose fibers. The peak melt temperature (~225°C) of PTT is about 30°C less than the peak melt temperature (~255°C) of poly(ethylene terephthalate). The interest in reinforcing PTT with cellulose fibers is also due to the "green" aspect of reinforcing a partially bio-based recyclable thermoplastic with fibers from a renewable resource. Synthesis of PTT is accomplished via a condensation reaction of 1,3-propanediol (PDO) with either terephthalic acid or dimethyl terephthalate. A fermentation process based on corn sugars may be used to manufacture the PDO. The composites of this study were compression molded from multiple plies of non-woven, fabric-like prepreg manufactured with wetlay papermaking equipment. These prepreg sheets contain a mixture of randomly-oriented PTT and cellulose pulp fibers. The specific cellulose pulp fibers used in this study were obtained from reclaimed news-paper and reclaimed kraft paper. These fibers are produced by milling post consumer newspaper and kraft paper into pulp fibers. The kraft pulp fibers are flat with a thickness of 1 to 2 µm and a width of about 30 µm; the fiber lengths vary from about 500 µm to 5000 µm. The news pulp fibers are also flat with a thickness of 1 to 2 µm and an average width of 64 µm; the fiber lengths average 1717 µm. These composites were tested in tension, flexure, and impact. The reinforcement of PTT with cellulose pulp fibers significantly improved the moduli and impact resistance of the PTT.

Use of Silane Technology in Crosslinking of Polyethylene-Wood Flour Composites

Magnus Bengtsson, Ph.D. Student, and *Kristiina Oksman*, Professor, Department of Engineering Design & Materials, Norwegian University of Science & Technology, Trondheim, Norway

Crosslinked composites, where wood is included in a three-dimensional network, will improve mechanical properties, long-term properties, and high-temperature properties compared to non-crosslinked composites. In this study the use of silane technology in crosslinking polyethylene-wood flour composites was investigated. Crosslinked composites were produced in a one-step process by using a co-rotating twin-screw extruder. The samples were stored in a simulated sauna and at room temperature for different periods of time to study the effect of crosslinking on storage conditions. Gel content and swelling experiments were used to determine the crosslinking characteristics. Storage in the high humidity sauna generated a higher degree of crosslinking than storage at room temperature. Moreover, the flexural properties and impact properties of crosslinked composites was compared with non-crosslinked composites. The flexural stress and strain were superior in the crosslinked composites compared with the non-crosslinked. The impact properties of the crosslinked composites were also significantly higher than in the non-crosslinked. Creep studies were also performed with the aim of determining if crosslinking could lower the creep of the composites. The internal structure of the composites was examined by SEM and Microsonde. X-ray mapping of the silicon signal was used to study where the silane was located in the composites. Furthermore, a study of how the long-term properties of the composites were affected by crosslinking was also conducted.

TUESDAY MORNING, MAY 24

CONCURRENT SESSIONS

SESSION 2A: ENGINEERING PROPERTIES

Stiffness Contribution of Woodfibers to Composite Materials

R. Cristian Neagu, Ph.D. Candidate, and *E. Kristofer Gamstedt*, Assistant Professor, KTH Solid Mechanics, Royal Institute of Technology, Stockholm, Sweden; and *F. Berthold*, Senior Research Associate, and *M. Lindström*, Research Manager, STFI-Packforsk AB, Stockholm, Sweden

Woodfibers have a low variability in mechanical properties as opposed to fibers from annual crops, which make them an attractive alternative as reinforcement in natural-fiber composites. This presentation describes a quantitative analytical experimental method to determine the contribution of the fibers to the elastic properties of the composite. A large variety of composites based on various woodfibers in an epoxy vinyl ester matrix were investigated. A micromechanical model and classical laminate mechanics were used to relate the elastic properties of the fibers to the elastic properties of the composite. The contributing Young's moduli of the fibers in the longitudinal direction were back-calculated from tensile tests of the composites. One finding is that there was an optimum in fiber stiffness as a function of lignin content and that unbleached fibers are more suitable than bleached

fibers for use as stiffening reinforcement. It was also found that industrially pulped hardwood fibers had higher stiffness than corresponding softwood fibers. The effects of hornification, prehydrolysis, and sulfite processing were also investigated. The results indicate that a mild defibration process that does not damage the cell-wall structure should be used so that the inherent high stiffness of the native fibers can be retained. The proposed method works well for ranking woodfiber candidates in terms of their contribution to composite stiffness.

“Theory of Mixture” in Creep Prediction of Thermoplastics-Based Natural Fiber Composites

Amit K. Pramanick, Ph.D. Student, and *Mohini Sain*, Professor, Centre for Biocomposites & Biomaterials Processing, Department of Chemical Engineering & Applied Chemistry, Faculty of Forestry, University of Toronto, Toronto, Ontario, Canada

Recently there has been an upsurge in the volume of load-bearing applications of natural fiber-based thermoplastic composites. Therefore the visco-elastic (hence durability) characterization of the natural fiber-based plastic composites is of paramount importance to the materials' long-term commercial success. To predict creep, one must derive a relationship between deformation, time, temperature, moisture, and stress. In this project, hollow extruded rice husk-HDPE beams were subjected to creep and recovery in flexural mode under varying temperature, stress, and relative humidity. Since the existing literature does not describe creep as a function of the constituent mechanical properties, we have striven to extend the “theory of mixtures” to develop a generic creep model that will relate the varying parameters. Due to the non-linear nature of both natural fiber and plastics, creep constants were determined with Schapery's model. The said constants were further compared with the constants predicted by the newly “extended theory of mixture”. The temperature-related shift factor was estimated as a function of the constituent activation energy. The validity of this assertion stems from the fact that at low stress fibers can sustain a good bond with the matrix. The combined effect of temperature and stress on creep strain was accommodated in a single analytical function where the interaction was shown to be additive. That means that the stress equivalency of temperature is possible. This constitutive equation will predict creep in the long run. Although stress dependency is non-linear, temperature dependency is linear and thermo-rheologically complex. Experiments also testify that relative humidity has a profound impact on creep. The above model may also be extended to incorporate the effect of relative humidity; however, the effect is non-linear and probably is related to diffusion coefficients of materials. Hence diffusion experiments are being conducted to understand this behavior completely. The above equation so is generic that it will also help us to predict creep in other composites based on plastics and natural fibers.

The Relationship of Interfacial Shear Strength to Composite Properties

Cheng (Peter) Zhang and *Jim Rogers*, Graduate Students, *John Simonsen*, Associate Professor, and *Kaichang Li*, Assistant Professor, Department of Wood Science & Engineering, Oregon State University, Corvallis, Oregon, USA

Several tests designed to investigate the interphase in wood-plastic composites are presented. A newly configured pullout test was used to measure interfacial shear strength. Maleic anhydride-based compatibilizers were studied. The test correlates with mechanical properties data under certain conditions. Deviations from correspondence were also found. Atomic force microscopy was used to probe the interphase in WPCs containing isocyanate compatibilizers. The test method and implications for designed composite development will be discussed.

Near Infrared Spectroscopy of Wood-Filled Polyolefins

Timothy G. Rials, Professor and Director, *S.S. Kelley*, Adjunct Professor, and *N. Labbe*, Research Associate, Forest Products Center, University of Tennessee, Knoxville, Tennessee, USA; and *Douglas J. Gardner*, Professor of Wood Science, Department of Forest Management and Advanced Engineered Wood Composites Center, University of Maine, Orono, Maine, USA

Wood-filled polyolefin composites are emerging as an important new class of material, providing new products in a variety of markets. Because these materials utilize an inherently variable raw material (wood), the process would benefit from sensor technology to monitor certain product performance characteristics in real time. Near infrared spectroscopy is an attractive option, providing an information-rich fingerprint for further analysis. In this work, a range of material properties was generated by formulating wood-plastic composites with dif-

ferent polyolefin matrix polymers and processing additives. Additionally, several post-die treatments were applied to effect crystallization and overall composite morphology. Principal component analysis of the near-infrared spectra readily differentiated between matrix polymer types, suggesting considerable sensitivity to formulation. Further, the influence of post-die temperature treatments was explored using projection to latent structures (PLS) modeling, and strong calibrations were developed. Although statistical analysis suggests very different sample populations, PLS models were developed for mechanical properties (bending modulus and modulus of rupture) with good results. Improvements in model quality may be possible with a less diverse material set. Opportunities to further develop this approach for process control of filled polymers will be considered.

Experimental Behavior of Hybrid Wood-Plastic Composite-FRP Structural Members for Use in Sustained Loading Applications

Matthew Dura, Graduate Research Assistant, Department of Civil & Environmental Engineering, *Roberto A. Lopez-Anido*, Associate Professor, Department of Civil & Environmental Engineering, *Habib J. Dagher*, Professor, Department of Civil & Environmental Engineering and Director, Advanced Engineered Wood Composites Center, *Douglas J. Gardner*, Professor of Wood Science, Department of Forest Management and Advanced Engineered Wood Composites Center, *Shane R. O'Neill*, Wood Plastic Composite Specialist and Project Manager, and *Katherine L. Stephens*, Graduate Research Assistant, Advanced Engineered Wood Composites Center, University of Maine, Orono, Maine, USA

In the design and construction of waterfront structures, there is a need for development of a corrosion-resistant, lightweight, cost-effective, and environmentally friendly structural material. Hybrid wood-plastic composite (WPC) - fiber-reinforced polymer (FRP) structural members would be corrosion resistant, and relatively lightweight (WPC-FRP). An additional advantage is that the WPC portion can be produced from recycled plastics and wood residuals. To use WPC in structural applications, a better understanding of the material properties and behavior under sustained loads must be obtained. In this presentation, a static and long-term experimental program is presented with coupon and full-size WPC samples. Coupon testing in tension, compression, and shear is conducted with the aid of a 3-D digital image correlation (DIC) system which allows a full field, non-contact measurement of strains on the material's surface. Full size, hybrid WPC-FRP members are also characterized experimentally in bending. This experimental response is used to generate and verify a non-linear model for long-term material behavior.

Design of Innovative Hollow Extruded WPC Sheet Piling

Melissa Kahl, Graduate Student, Department of Civil & Environmental Engineering, *Habib J. Dagher*, Professor, Department of Civil & Environmental Engineering and Director, Advanced Engineered Wood Composites Center, *Roberto A. Lopez-Anido*, Associate Professor, Department of Civil & Environmental Engineering, *Douglas J. Gardner*, Professor of Wood Science, Department of Forest Management and Advanced Engineered Wood Composites Center, and *Matthew Dura*, Graduate Research Assistant, Department of Civil & Environmental Engineering, University of Maine, Orono, Maine, USA

This presentation describes development of an innovative hollow-z-section sheet pile die profile for production of extruded wood-plastic composites (WPC). Optimized void geometry and placement are selected to maximize profile mechanical properties, and the resulting typical section dimensions are given. The proposed extruded sections are then evaluated for both web crippling, local wall buckling, and overall bending moment capacity. Preliminary design tables containing the maximum allowable wall height for each section geometry under a variety of backfill conditions and overburden load conditions are given. The design criteria used in developing the tables include strength limit states, initial and long-term deflection limit states, as well as considerations for long-term effects, and creep. The new hollow WPC sections are compared with all-vinyl sheet pile sections currently available on the market. The material efficiencies between polypropylene-WPC and all-vinyl are calculated, and the cost-benefits of WPC are estimated. The new profile section geometry provides moment of inertia and section modulus increases of up to 25% compared to solid vinyl sections of the same cross-sectional area and depth.

SESSION 2B: ADHESION AND THE INTERFACE

Assessing Interfacial Behaviors of Natural Fiber-Plastic Composites by Fluorescent Microscopy

Warren J. Grigsby, Senior Scientist, and *Armin Thumm*, and *Marc Gaugler*, Scientists, Biomaterials Engineering Group, Forest Research, Rotorua, New Zealand; and *Hannes Klepser*, University of Reutlingen, Reutlingen, Germany

Natural fibers such as wood, hemp, or flax are increasingly added to polymers to enhance the performance of the resulting composites. Improvements are only possible if there is good adhesion between the polymer and fiber constituents, and the fibers are relatively uniform and unimpaired by fiber damage. Fluorescent microscopy has been employed to observe interfacial behaviors in plastics compounded with natural fibers. Both petrochemical and bio-derived thermoplastics were fluorescently labeled before combining with woodfibers. Wood-plastic composite (WPC) profiles were then generated by hot pressing, extrusion, and injection molding under a range of conditions and the combinations then microscopically examined for differences in interfacial behaviors between the fiber and plastic, characterizing any cell wall interaction, formation of voids between the fiber-plastic interface and, if any, the extent of fiber lumen filling by polymer. In assessing the efficacy of this approach, results suggest the use of fluorescent labeling techniques worked well for some fiber/plastic combinations where WPC processing temperature and residence times were kept relatively low.

Chemical Imaging of Wood-Polypropylene Composites

David P. Harper, Assistant Professor, Forest Products Center, University of Tennessee, Knoxville, Tennessee, USA; and *Michael P. Wolcott*, Professor and Research Director, Wood Materials & Engineering Laboratory, Washington State University, Pullman, Washington, USA

Recent investigations of wood-plastic composites have revealed a detrimental effect of using lubricant systems in production. This includes nullifying part or all of the mechanical benefit of using a polar compatibilizer, maleic anhydride polypropylene (MAPP), in the composite formulation. Speculation exists whether the mechanism is lubricant interaction with the wood surface or with the bulk polymer that results in morphological and property changes in the composite. This research investigates the location of the material constituents and the impact on the chemistry of the interphase and wood-PP interface. This investigation utilizes lubricants labeled with deuterium in conjunction with Fourier transform infrared spectroscopy (FTIR). The deuterium labeling allows for the separation of individual lubricants from all other constituents. The MAPP used in this study is not labeled. All of the deuterium labeled lubricants, used without MAPP, revealed their expulsion from the wood interface during crystallization. However, MAPP coupling agent was found to exist near the wood, but it is unclear if any covalent bonding occurred with the hydroxyl functionality on the wood surface. The addition of zinc stearate lubricants appears to nullify the activity of the anhydride functionality near the wood surface as evidenced by a shift in the FTIR spectra to the hydrolyzed form of the coupling agent. Most of the additives collect at the edges of the spherulites in mostly amorphous regions of the material. The consequence of this morphology may be a weak interface between crystallites.

The Influence of MAPP on Crystalline Development in Polypropylene Matrix Composites

Morwenna Spear, Research Officer, and *Callum Hill*, Senior Lecturer in Wood Science, School of Agricultural & Forest Sciences, University of Wales, Bangor, Gwynedd, United Kingdom

Four forms of maleic anhydride-graft polypropylene (MAPP) were used to prepare specimens for hot stage microscopy and microtensile testing. In most cases the MAPP matrix specimens did not exhibit transcrystallinity on hemp and flax fibers, and in polypropylene-MAPP matrices the incidence of transcrystallinity was also reduced compared to polypropylene matrices. The influence of fiber preparation and chemistry, and of MAPP molecular weight and graft type, on the resulting crystalline morphology are discussed. This is related to trends seen in microtensile testing. It was found that highly-grafted MAPP has a reduced ability to crystallize and can be excluded from developing spherulites during cooling of the quiescent melt. Where the highly-grafted MAPP coated the fiber surface, this resulted in reduced nucleation and prevented transcrystalline development. MAPP with a lower graft density of anhydride remained blended with the matrix and increased the spherulite nucleation rate.

The Effect of Woodfiber Modification and Particle Size on Wood-Plastic Composite Performance

Lance W. Gallagher and *Smith T. Sundar*, Graduate Students, and *Armando G. McDonald*, Associate Professor, Wood Chemistry & Composites, Department of Forest Products, University of Idaho, Moscow, Idaho, USA; and *Michael P. Wolcott*, Professor and Research Director, Wood Materials & Engineering Laboratory, Washington State University, Pullman, Washington, USA

There has been considerable interest in the use of inorganic-based nano-sized particles as reinforcers in thermoplastics, because they exhibit a unique set of properties (higher heat distortion temperature, stiffness, and toughness). Improved coupling takes place between the particles and the matrix due to the large surface area of the nano-sized particles, which facilitates stress transfer to the reinforcing phase. The expectation is to incorporate this idea into wood-plastic composites (WPC). Currently woodfiber sizes utilized by industry range from 20 to 100 mesh (850 to 180 μm). These composites have end applications such as decking, however these products lack the performance properties required for structural applications. This study is investigating (i) the effect of reinforcing WPC with micron (~25 μm) sized wood particles and (ii) chemically tailoring the wood surface with isocyanate-anchored alkyl chains to improve the interface between the wood and the matrix, in order to enhance WPC performance. Commercial maple woodfiber was ball milled and screened into discrete size fractions (>100, 100-200, 200-300, 300-400, and <400 mesh). Alcohol (C2 to C18) modified diphenyl-methane-4,4'-diisocyanates were employed for surface modification of woodfiber (200-300 mesh) and the modified fiber was characterized by FTIR spectroscopy. High-density (HDPE) based wood-plastic composites (WPC) were made from the sized woodfiber fractions (10 to 50%) and by modified woodfiber (10, 30, and 50% loading) by compounding followed by injection molding. Tensile modulus was shown to increase (i) with an increase of wood loading and (ii) with a decrease in woodfiber size. The toughness of the WPC was shown to increase with a decrease in woodfiber size. However, the tensile strength was shown to be relatively constant as a function of loading and particle size. Slight differences in WPC tensile properties were observed between the materials made from the various modified fibers against control fibers. Evidence suggests that the production of voids in the modified fiber WPC samples is limiting performance. DSC was used to determine the extent of HDPE crystallization as a function of woodfiber size and fiber modification. The flow characteristics of the WPC polymer melts were examined by dynamic parallel plate rheometry. HDPE crystallization onset was observed at 124°C for all samples. The complex viscosity of the WPC melt was shown to positively increase as a function of woodfiber size as well as wood loading. The combined effects of woodfiber modification, fiber size, and coupling agents on extruded product performance will also be discussed.

The Application of Flame Surface Pre-Treatment to Promote Structural Adhesive Bonds in Wood-Plastic Composite Laminates

Douglas J. Gardner, Professor of Wood Science, Department of Forest Management and Advanced Engineered Wood Composites Center, *Shane R. O'Neill*, Wood Plastic Composite Specialist and Project Manager, and *Matthew Peterson*, Graduate Research Assistant, Advanced Engineered Wood Composites Center, University of Maine, Orono, Maine, USA; and *Jonathan Robinson*, Undergraduate Student, Milwaukee School of Engineering, Milwaukee, Wisconsin, USA

The formation of waterproof, structural adhesive bonds in wood-plastic composite (WPC) materials is extremely challenging because of the poor adhesion properties of polyolefinic polymers such as high-density polyethylene (HDPE) and polypropylene (PP) in their natural state. Both HDPE and PP exhibit low surface energy, nonpolar surfaces that are poorly wetted by most polymeric adhesive systems such as epoxies. In this study, flame pre-treatment is explored as a means to modify and enhance the WPC surface towards adhesive bonding with epoxy adhesives. HDPE, PP, and polystyrene (PS) WPC composite lumber was manufactured on a Davis Standard Woodtruder at a 60% wood/40% polymer ratio. The resulting lumber was planed, sanded, or left in the natural state prior to flame treatment using a handheld propane torch. Flame treated and control WPC laminates were manufactured using epoxy adhesive, and the resulting adhesive bonds were tested for shear strength and material failure following ASTM D 905. Additional laminate samples were manufactured and evaluated for delamination following ASTM D 2559. The application of the flame treatment significantly increased the bonding properties of the WPC laminates as evidenced by the improved shear strength, material failure, and

absence of delamination when exposed to the cyclic testing of ASTM D 2559. Scale-up of WPC flame pre-treatment to the pilot scale will also be discussed.

DMTA Analysis of Interface Adhesion in Wood-Plastic Composites

Carlos A. Correa, Associate Professor, Postgraduate Program in Materials Engineering & Science, Universidade São Francisco, Itatiba, São Paulo, Brazil; *C.A. Razzino* and *E. Hage, Jr.*, Department of Materials Engineering, Universidade Federal de São Carlos, São Carlos, São Paulo, Brazil

The main accomplishment of compounding wood waste flour (WWF) with thermoplastics is an increase in rigidity and specific strength as compared to mineral-filled polymers. The choice of the coupling agent may determine the final composite formulation as well as the adhesion efficiency on the matrix-filler interface. Maleated polypropylene (PP-MAH) with varying MAH content and melt flow indices has been used as a coupling agent in polypropylene-wood waste composites. Changes in interface adhesion with the addition of PP-MAH were evaluated through dynamic-mechanical thermal analysis (DMTA) by applying a criterion based upon the relative mechanical damping ($\tan \delta$) values of the composites as a function of temperature. The DMTA Adhesion Factor has shown that independent of the PP-MAH amount in the composite formulation and its MAH content, all formulations had their matrix-filler adhesion improved. Evidence of chain mobility at the filler-matrix interface has been related to an increase in the Adhesion Factor above T_g , especially in homopolymer formulations. In general, the composite with the coupling agent with the lowest molecular weight presented the lowest strain at failure, best gain in Young's modulus, and stress at yield. A much more rigid interface and better adhesion can be related to low values of the Adhesion Factor. Improvements in mechanical properties were corroborated by electron microscopy images of the interface that clearly illustrate changes in the wettability of the filler by the matrix in the presence of the maleated polypropylene used as coupling agent.

TUESDAY AFTERNOON, MAY 24

CONCURRENT SESSIONS

SESSION 3A: DURABILITY I

Improvements in Weathering Characteristics of Wood-Plastic Composites

Dilpreet S. Bajwa, Director of Research & Development, and *David Bruce*, EPOCH Composite Products, Inc., Lamar, Missouri, USA

Wood-plastic composites (WPCs) have shown phenomenal growth over the last decade. These products are typically manufactured under three colors; redwood, cedar, and grey. These colors show significant shift in color (Delta E) over a short period of natural exposure. An extensive study was conducted to understand the affect of resin, wood flour, color pigments, and regrind towards the colorfastness of WPC products. The test sample formulation was comprised of polyethylene resin, pine wood flour, color pigments, and other additives. Two color samples, redwood and cedar were manufactured using a laboratory mixer and compression molding press. Further, these samples were exposed to both natural and accelerated aging conditions. The results presented in this paper are at 12 months of natural weathering and 2000 hours of accelerated weathering under xenon arc light. The change in color (Delta E) varied from 0.29 to 13.49 for various samples. Concentrated color pigments, UV/AO loaded color pigments, and color coated wood flour improved colorfastness. However, amount of regrind, mixed-metal oxide pigments, and commonly available color pigments did not show significant improvement in the weathering characteristic of WPCs.

Chemical Changes that Occur During the Weathering of Wood-Plastic Composites

Armando G. McDonald, Associate Professor, Wood Chemistry & Composites, and *James S. Fabiyi*, Ph.D. Student and Graduate Research Assistant, Department of Forest Products, University of Idaho, Moscow, Idaho, USA; and *Michael P. Wolcott*, Professor and Research Director, Wood Materials & Engineering Laboratory, Washington State University, Pullman, Washington, USA

In North America, wood-plastic composites (WPCs) have emerged as a new material and over the past decade numerous full-scale production facilities have been set up to meet the demand of a growing deck-

ing market. However, the durability issues surrounding the use of WPC are of great concern. The exposure of polymeric materials such as WPC to environmental and artificial atmosphere changes their properties and external appearances with some modification of their surfaces. It has been reported that when wood is exposed to the outdoors above ground, a complex combination of chemical, mechanical, and light energy factors contribute to what is described as weathering. In plastics this results in embrittlement and color changes. The purpose of this study is to get a better understanding of the chemical changes that occur to the wood and plastic components in WPC (based on Maple and HDPE) upon weathering (natural and accelerated). Several procedures (xylene extraction, pyrolysis gas chromatography-mass spectrometry (GC-MS), Fourier transform infrared (FTIR) spectroscopy, and differential scanning calorimetry (DSC)) have been employed to specifically analyze chemical changes. Xylene was used to solubilize and isolate HDPE (~40% yield) from the WPC to form film for subsequent analyses (FTIR and DSC). Pyrolysis GC-MS was employed to determine the compositional changes that occur in the WPC and the results show that lignin content was reduced upon weathering at the WPC surface. DSC analysis was employed to examine changes in HDPE structure and the results showed that there was increase in HDPE crystallinity upon weathering. The extent of oxidation on the WPC surface was examined by FTIR as an increase of carbonyl peak ($C=O$, 1725 cm^{-1}). Additional information on the surface composition was also observed by FTIR analysis and will be further discussed. The long-term outcome of this research is to develop WPC formulations with enhanced performance attributes based on our understanding of the weathering mechanism.

Analysis of Environmental Impact on Highly-Filled Wood-Plastic Composites by Laboratory Simulation and Full-Scale Testing

Georg Oberdorfer, Research Associate, and *Michael Golser*, Senior Scientist, Holzforschung Austria, Vienna, Austria

Despite its still small volume, the European market for wood-plastic composites (WPCs) shows considerable potential as growth rates and industry interest continue to rise. As in North America, broad market acceptance in Europe is substantially affected by the lack of WPC-standards. Our research program aims at helping to create the scientific basis for standardization work in Europe. Testing standards must be chosen, modified, or developed based on material behavior, in-service conditions, and method-practicability. In the first project, phase durability, mechanical and physical properties of WPC-products were evaluated using European, American, and international standards for wood, wood-based composites, and plastic. Ongoing studies improve our understanding of relationships between material composition, material properties, and product performance in service. For outdoor use, WPC-products are being marketed as durable, dimensionally stable, maintenance-free, etc. although long-term experience, knowledge of material responses to changing conditions, and understanding of governing mechanisms are very limited. Furthermore, published scientific work covers mainly WPCs with fiber loadings of up to or around 50% wt. while polyolefin-based WPC-products with fiber loadings of 60% to 85% wt. (and thus dramatically altered characteristics) are most common in Europe. Extruded products with high-fiber loadings from commercial sources and controlled laboratory production were investigated. For comparison, commercial U.S. products were included in the testing. In accelerated laboratory and outdoor weathering tests, samples were exposed to different temperature, humidity, and radiation regimes over extended periods of time. Results regarding mechanical and physical properties as well as suitability of test methods are presented.

The Influence of Moisture on the UV Weathering Properties of HDPE/WF Composites

Nicole M. Stark, Chemical Engineer, USDA Forest Products Laboratory, Madison, Wisconsin, USA

Wood-plastic lumber is promoted as a low-maintenance high-durability product. After weathering, however, wood-plastic composites (WPCs) often fade and lose mechanical properties. Differences in weathering can affect the rate and amount of change due to weathering. In this study, 50% wood-flour-filled high-density polyethylene (HDPE) composite samples were injection molded. Composites were exposed to two accelerated weathering cycles in a xenon-arc type weathering apparatus; either UV light with water spray or UV light only. Results after immersion in a water bath followed by drying were compared to the results obtained after accelerated weathering. Density profiles through the composite thickness obtained after exposure show

that the density at the surface of the composite decreases upon exposure to UV light and water spray. The composites lightened less when they were exposed to UV light only, or immersed in a water bath, compared with exposure to UV light with water spray. The change in MOE and strength was also much less when the composites were exposed to only UV light or immersed in a water bath. The results of this study demonstrate that exposing WPCs to moisture in combination with UV light is necessary for drastic changes in appearance and mechanical property changes to occur. This is likely a result of the water spray washing away the degraded layer and wood extractives during weathering, as well as causing the wood-plastic interface to be compromised through dimensional changes in the wood particles.

SESSION 3B: ADDITIVES

Ionomer as a Multi-Functional Ingredient for Value-Added Wood-Plastic Composites

Tieqi Li, Post-Doctoral Fellow, and *Ning Yan*, Assistant Professor, Department of Chemical Engineering & Applied Chemistry, Faculty of Forestry, University of Toronto, Toronto, Ontario, Canada

Wood-plastic composites (WPCs) have enjoyed considerable commercial success in recent years. Certain fundamental problems, however, still limit further market expansion of this type of material. Poor impact resistance, low creep resistance, and limited moisture resistance and dimensional stability are the most commonly encountered problems that limit the application of WPCs. Hence, persisting efforts are being made to investigate the mechanisms of these problems and to explore strategies for overcoming them at reasonable cost. As most of these problems either originate from or are related to the high wood loading and the weak wood-plastic interface, an ideal modifier should be able to improve wood-polymer interfacial bonding and matrix toughness. Additives that bear the desired bonding capacity with wood and proper compatibility with the matrix resin are naturally a good candidate for such modification. In this study, ionomer resin was investigated in terms of its effect on performance of high-density polyethylene (HDPE)/maple composites. It was found that the ionic copolymers had positive effects on impact resistance and static strength, etc. Thermal analysis and rheology studies indicate that the modifications thus obtained were related to the improved interfacial status and the changes in matrix morphology. The implication of these results will be discussed in the presentation.

Controlled Architecture Materials-Based Processing Aid for Polymer Wood Composites

James Nelson, Controlled Architecture Materials Project Leader, 3M / Dyneon, and *Ryan Marx* and *John Longabach*, Advanced Research Engineers, 3M Corporate Process Technology Center, St. Paul, Minnesota, USA

Polymer wood composites (PWC) are currently attracting considerable attention for use as unique structural materials in construction (decking) markets and in the automotive industry. Melt processing of these highly-filled polyolefin composites with filler levels of 40-70% wood flour, can be a challenge. Presently, PWC materials are often produced with melt fractured surfaces and with some burning or decomposition of the wood flour due to shear heating. Traditionally, melt fracture elimination is achieved through use of fluoropolymer additives, which are capable of alleviating melt fracture in many polymeric materials by coating the processing equipment and thereby producing interfacial slip between the processing equipment and the polymeric material. Interfacial slip is the reduction of shear stress between the polymer melt and the processing equipment. The incorporation of wood flour adversely affects the efficacy of the fluoropolymers incorporated into the melt processable mixture as a processing aid. Such fillers can interfere with the ability of the fluoropolymer to create interfacial slip between the polymeric material and the processing equipment. Additionally, an increase in the amount of processing aid in the polymeric mixture does not reduce the melt fracture of the polymeric material to acceptable levels. Our current effort is focused on the development of PWC additive packages, which address the need for improved surface features, stain resistance, anti-drip, and offer other advantageous properties such as improved production rates (throughput) and physical properties. Our initial efforts in this area will be described.

Recent Advances in Talc-Reinforced Wood-Plastic Composites

Richard J. Clark, Senior Market Development Manager, and *O. Noel*, Luzenac America, Inc., Centennial, Colorado, USA

The initial examination of talc in wood-plastic composites focused on the effect of talc on Modulus of Rupture, Modulus of Elasticity, Creep Behavior, and water absorption. Recent studies have examined processing efficiency, resin replacement, variables affecting color, and the effect of mechanical properties as a function of water absorption.

Effect of Defined Waxes and Coupling Agents on Moisture Behavior of Injection Molded Woodfiber-Reinforced PP Composites

Andrzej K. Bledzki, Professor, *Volker E. Sperber*, Senior Lecturer, and *Klaus Specht* and *Monika A. Letman*, Ph.D. Students, Institut für Werkstofftechnik, Kunststoff- und Recyclingtechnik, University of Kassel, Kassel, Germany; and *Armanda Viksne*, Leading Researcher, Department of Polymer Materials, Riga Technical University, Riga, Latvia

Woodfiber-reinforced composites are used in a wide range of applications and processing systems. Special additives have to be used for enhanced physical properties as well as for sufficient processing properties in extrusion or injection molding. Woodfiber-reinforced polypropylene composites (WPCs) with a fiber content of 40-50% by weight were prepared with two types of woodfibers (hardwood fiber and softwood fiber). The key for good adherence between wood and PP is the chemical modification of the fibers with optimal addition of a coupling or hydrophobic agent. Within this framework, the influence of the grafting grade and molecular length of several MAH-PP-copolymers were investigated by testing injection-molded hardwood PP composites after different pre-processing techniques such as agglomeration with a cascade mixer, compounding with a twin-screw extruder, or 'plastagglomeration' were applied. Generally, the high viscosities of the woodfiber-reinforced thermoplastics are another disadvantage of these materials. With processing lubricants, commonly waxes, the flow action can be decreased for fiber friendly thermoplastic processing. In this case different types of waxes in injection molded hard and soft woodfiber-reinforced PP were investigated. Tensile, bending, and impact test measurements of these woodfiber-reinforced polypropylenes are described. Particularly, the moisture behavior and mechanical properties of the composites were tested after conditioning in water; and cyclic climate and wet-drying tests were carried out. Moisture absorption and desorption is very important to the physical properties and depends extensively on the type of woodfiber and additives used. The results show that the properties are partially or fully reversible, especially in samples modified with MAH. Wax and MAH influenced the mechanical properties similarly. Modified composites (wax or MAH) showed lower water absorption compared to non-modified composites. The cyclic water absorption of the composites increases asymptotically and is approximately 50% lower than the static water absorption.

WEDNESDAY MORNING, MAY 25

CONCURRENT SESSIONS

SESSION 4A: DURABILITY II

Sorption of Water in Hemp and Coir Fibers

Thu Nga Ho, Graduate Student, and *Anh-Dung Ngo*, Professor, Department of Mechanical Engineering, Université du Québec, Montréal, Québec, Canada

In searching for green materials, automotive and construction industries have been interested in composites reinforced with natural plant fibers as alternative materials for glass-fiber reinforced composites in structural applications with modest demands on strength reliability. It has been known that the high level of moisture absorption by natural fibers, the poor wettability, and the insufficient adhesion between untreated fibers and the polymeric matrix lead to bonding failure with age. Moreover the absorbed moisture has many detrimental effects on the mechanical performance of these fibers. Therefore, understanding the mechanism of moisture diffusion and moisture-induced damage of natural fibers is very important to improve the long-term performance of composites reinforced with these fibers. In this study, the water absorption behavior of hemp and coir fibers at 23, 40, 50, 60, 70, 80°C, was studied. Experimental results showed that the hemp fibers were more affected by water than coir fibers. Both fibers displayed a

two-stage diffusion behavior, with the first stage controlled by the capillary action showing Fickian diffusion behavior and the second stage controlled by relaxation of the fibers that showed non-Fickian anomaly. The increase of diffusion with temperature indicated the activation of the diffusion process at higher temperature in both the first and second stages. The water uptake was found to increase with increasing temperature. The thermodynamic parameters of the sorption process, such as diffusion, sorption, permeability coefficients, and activation energies, were estimated.

Water Absorption by Wood-Plastic Composites in Exterior Exposure

Marek Gnatowski, Technical Director, Polymer Engineering Co. Ltd., Burnaby, British Columbia, Canada

Water absorption by wood-plastic composites (WPC) is an important and controversial issue affecting warpage, dimensional stability, and resistance of material to freeze-thaw cycling as well as fungal growth and decay. The objective of the work presented is to identify water absorption and water distribution in experimental WPC exposed to exterior conditions, and comparison of these results with the standard water absorption test used by industry. WPC formulations used, as well as processing conditions, were selected in such a way that the obtained WPC materials showed water absorption in equilibrium and absorption kinetics representative for a large variety of commercial products available on the North American market. Randomly selected boards from the extrusion run were exposed to exterior weathering in Vancouver (BC) in sun or in shadow. The duration of the exposure was 21 months. After collection, the samples were cross-sectioned into small specimens for moisture content (MC) evaluation. The obtained results indicated that there is no obvious correlation between water absorption of WPC measured according to industry standard and MC in the same materials exposed to exterior conditions. WPC will absorb a significant amount of moisture when exposed to an exterior environment. The core may have very low MC while the surface layer may be significantly saturated with water. The presence of zinc borate in the WPC formulation seems to reduce water absorption by WPC.

Resistance of HDPE/Wood-Flour Composites to Cyclic Freezing and Thawing Exposures

Laurent M. Matuana, Assistant Professor, Department of Forestry, Michigan State University, East Lansing, Michigan, USA

This study examined the freeze-thaw durability of wood-plastic composites (WPCs). Blends of high-density polyethylene, wood flour (either pine or maple), and lubricant were processed in a conical twin-screw extruder and exposed to accelerated cyclic freeze-thaw actions according to ASTM standard D6662. The durability of exposed WPC samples without and with 2% coupling agent (maleated polyethylene) was assessed in terms of dimensional stability, flexural properties, and porosity. The dimensional stability of the samples was not affected by freeze-thaw cycling actions. By contrast, freeze-thaw actions altered the adhesion in WPCs without coupling agent, which resulted in a significant flexural property loss (13% loss in MOR and 35% loss in MOE), regardless of wood filler species. Porosity results confirmed a decrease in interfacial adhesion in WPCs without coupling agent since larger pores, particularly in the range between 0.1 and 10 μm , were observed in WPCs exposed to freeze-thaw actions. Interestingly, the deleterious effect of freeze-thaw actions in WPCs was offset by adding a small amount of coupling agent in the composites. The strength and stiffness losses of the exposed WPC samples with coupling agent were 1% and 18%, respectively.

The Effect of Manufacturing Variables on Mold Susceptibility of Wood-Plastic Composites

Peter E. Laks, Professor, J. Klay Vehring, Graduate Student, Steven A. Verhey, former Ph.D. Student, and Dana L. Richter, Research Scientist II and Adjunct Associate Professor, School of Forest Resources & Environmental Science, Michigan Technological University, Houghton, Michigan, USA

Mold growth on building products, including wood/thermoplastic decking, has developed as an important issue over the last 5 years. Very little information is available in the literature on mold susceptibility of wood-plastic composites (WPCs). Basic WPC manufacturing variables (wood content, lubricant content and type, processing temperature profile, surface roughness, and moldicide type and content) were evaluated for their effect on the mold susceptibility of WPC manufactured using a lab scale extruder. Increasing the wood content, surface roughness, and lubricant content resulted in more mold growth on the composite. Incorporating moldicides (chlorothalonil, zinc

borate, and IPBC) reduced the mold growth. Extruder barrel temperature had a complicated effect on mold susceptibility. These results may help manufacturers choose manufacturing variables to reduce mold susceptibility of their WPC products.

Comparison of Agar (MEA and PDA) and Soil Block Tests for Assessing Decay of Wood-Plastic Composites

José Antonio Silva Guzmán, Associate Professor, Department of Wood, Cellulose & Paper, Universidad de Guadalajara, Zapopan, Jalisco, México; and Jeffrey J. Morrell, Professor, and Barbara L. Gartner, Associate Professor, Department of Wood Science & Engineering, Oregon State University, Corvallis, Oregon, USA

The ability of malt extract agar (MEA), potato dextrose agar (PDA), and a modified traditional soil block test soil to enhance fungal attack of maple wood-plastic composites (WPCs) (60% maple, 40% polypropylene, thickness, 0.5 mm) was examined. Moisture content and weight loss were used to assess the extent of decay of WPCs. Rates of decay in WPC specimens exposed in agar were greater than in those exposed in the soil block tests. Both MEA and PDA enhanced decay of WPCs. PDA was a better medium for *Trametes versicolor* with 49.1% weight loss of the woody component of the composite, while MEA was a better medium for *Gloeophyllum trabeum* with 38.3%. Both MEA and PDA were suitable media for *Postia placenta* (39.8% and 47.7%, respectively). All tested specimens exhibited weight losses from 20% to 49% when exposed in agar tests for 12 weeks, and 25% to 36% when exposed in soil block test regardless of the fungus or concentration media tested. A strong relationship was found between weight loss and moisture content; WPC specimens that experienced severe decay also exhibited high moisture content. The results indicate that WPC decay can be accelerated using both agar and soil as media.

The Advanced Protection Against Algae, Fungi, and Termites Created by the Use of Biocides in WPC, and the Difference Between Metal and Metal-Free Formulations

Marc Thometschek, Manager, Beologic nv, Sint Denijs (Zwevegem), Belgium

Wood-polymer composites (WPC) have been successfully commercialized as a durable alternative to wood for a large variety of applications. Today, it is known that some of these materials are not completely maintenance free. It is shown by different publications that moisture content at the surface of WPC might exceed the minimal level that is needed for fungal and algae growth, leading to a decline of the visual appearance and material properties of the WPC. Official biological tests for the evaluation of fungicidal and algacidal activity in these matrices do not exist yet for Europe. In this presentation, we propose tests that are used successfully for the biological evaluation of plastics and wood. For fungicidal and algacidal activity, the standard test ISO 16896 was performed. WPC samples incorporated with and without BETHOGUARD®, a broad spectrum algacidal and fungicidal oxathiazine derivative, were investigated. Samples without BETHOGUARD® were completely overgrown, however, tests performed according to ISO 16896 have shown that 1250 ppm BETHOGUARD® is needed for the control of fungi and algae. In addition, standard soil burial tests were used to evaluate the activity of BETHOGUARD® against soft rot fungi. After 1 ½ years, no weight loss or decline of the visual appearance of the samples was observed. We have learned that other metal-based formulations, for example zinc borates, also tend to perform very well, although higher concentrations are needed. Not taking economics into account, metal-free biocides are certainly the way to go from an environmental point of view. In our research, we try to evaluate and determine the performance of these different types of formulations and their ideal concentrations. Because BETHOGUARD® is a metal and halogen free biocide of a new chemical class, it is very promising for the advanced protection of WPCs.

SESSION 4B: NANOCOMPOSITES

Cellulose-Based Nanocomposites

Fabíola Vilaseca, and Ton Peijs, Professor, Department of Materials, Queen Mary University of London, London, United Kingdom

The processing of polymeric composites filled with nanosized rigid particles is an emerging area that is attracting both scientific and industrial interest. Over the last few years, increasing effort has been devoted to the use of nanoparticles obtained from natural sources as reinforcing elements for polymeric matrices. In this sense, cellulose microfibrils are an interesting alternative to mineral fillers in multi-component polymer systems: their low cost, low density, high stiff-

ness, consumable property, and biodegradability constitute major incentives for their uses. It is well-known that native celluloses, when subjected to strong acid hydrolysis, break down into microcrystalline cellulose with almost no weight loss. Marine animals also synthesize high crystalline cellulose microfibrils developing tunicates. The hydrolysis of these microfibrils yield cellulose whiskers, which are rigid rod shaped monocrystalline cellulose particles. The high interest of such whiskers is their large aspect ratio and high Young modulus (from 130 to 150 GPa) which provides them with a great potential for the reinforcement of polymer matrices. Furthermore, it has been reported that cellulose growing from green algae and some bacteria, can possess higher crystallinity than that obtained from plant resource. Because of its high tensile strength and water-holding capacity, bacterial cellulose has been used as a raw material for many applications. This presentation will give an overview of various sources of cellulose nanofibers and will discuss the potential of such nanofibers as reinforcing elements for polymer matrices.

Composites from Polyurethane and Cellulose Nano/Microcrystals

N.E. Bellesi, Ph.D. Student, Department of Chemical Engineering - Institute of Materials Science & Technology (INTEMA), Universidad Nacional de Mar del Plata, Mar del Plata, Argentina; *M.L. Auad*, Research Associate, Composites Center, University of Southern California, Los Angeles, California, USA; and *N.E. Marcovich*, Associate Professor, and *Mirta I. Aranguren*, Professor, Department of Chemical Engineering - Institute of Materials Science & Technology (INTEMA), Universidad Nacional de Mar del Plata, Mar del Plata, Argentina

Cellulose is a polydisperse linear polymer of poly- β (1,4)-D-glucose which is biosynthesized by different living species in the form of threadlike rods called microfibrils. The microfibrils consist of cellulose chain aggregates in which the molecules are stabilized laterally by hydrogen bonds between hydroxyl groups and oxygens of adjacent molecules. They contain crystalline regions linked by amorphous domains that act as structural defects and are responsible for the transverse breakdown of the microfibrils into shorter crystalline whiskers upon the action of strong acids. During sulfuric acid treatment of cellulose, grafting of ionic species (sulfates) leads to the formation of stable colloidal suspensions of the crystals. These cellulose crystals have the potential for excellent mechanical performance because of low density in combination with high moduli and tensile strength. These facts make them very attractive for the use as matrix reinforcement in the production of composites. So far, the production of cellulose nanocomposites has been restricted to aqueous-based polymer materials mainly because of the difficulty of the nano/microcrystals dispersion in organic solvents. However, replacing water by a strong polar organic solvent, such as dimethylformamide (DMF), opens new possibilities for the use of cellulose as reinforcement in other polymeric matrices. In particular, DMF has been used as the solvent in the production of PU films. The use of polyurethanes as a matrix leads to a large number of possible applications, such as thermal insulators (structural foams), specialty coatings, or biomedical materials (catheters, etc.). The purpose of this work was to obtain cellulose nano/microcrystals free of defects through hydrolysis with sulfuric acid and to develop a technique for dispersing these crystals in a non-aqueous solvent, such as DMF. Afterwards, polyurethane elastomeric films reinforced with the nano/microcrystals of cellulose were obtained. Cellulose nano/microcrystals from microcrystalline cellulose were obtained in an aqueous suspension. After carefully washing and freeze drying the nano/microcrystals, they were redispersed in DMF. Stable well-dispersed cellulose crystal suspensions in DMF were obtained. A flexible polyurethane was used as the matrix for the composites. It was based on an isocyanate prepolymer and a polyol mixture containing 60wt% of diol and 40wt% of polyol. The DMF-cellulose suspension was mixed with the polyol mixture and dispersed by ultrasonication. Then the isocyanate was added, the mixture was cast into a cylindrical mold and the DMF was evaporated. The curing reaction was carried out at 70°C under pressure, to avoid bubbles. Films of about 0.1 mm thickness, with cellulose concentrations ranging from 0 to 10wt%, were obtained. The materials obtained in the study were evaluated according to their dynamic mechanical response, the morphology as revealed by microscopy, and their capability to retain their original transparency.

Structural Evolution of Cellulosic Nano-Fibers from Fiber Bundles

Mohini Sain, Professor, and *Arpana Bhatnagar*, M.Sc. Candidate, Centre for Biocomposites & Biomaterials Processing, Department of Chemical Engineering & Applied Chemistry, Faculty of Forestry, University of Toronto, Toronto, Ontario, Canada

Natural cellulose fibers are gaining acceptance as glass fiber replacements in composite manufacturing. Currently, only long fibers from plants such as hemp, flax, sisal, jute, etc. are used. However, within the cell walls of all plant cells, there is a second level of fiber structure on a very small scale. These are bundles of cellulose nanofibers with a diameter range between 5 to 50 nm and lengths of thousands of nanometres. Theoretically these nanofibers can have stiffness up to 130 GPa and strength up to 7 GPa. In the present work, a novel technique was developed to extract cellulose nanofibers from long fibers using a physical-chemical defibrillation process. The average aspect ratio was more than 85, confirming the capability of nanofibers as reinforcing materials in composite manufacturing. TEM images also suggest that residence time for defibrillation strongly influence the nanofiber yield. For a more uniform distribution higher residence time is recommended. Defibrillation with higher residence time did not produce better defibrillation and was more energy consuming. Nanofiber structure was investigated by atomic force microscopy and transmission electron microscopy. Selective chemical treatments increased cellulose content to 94% from 73%. The calculated aspect ratio (length/diameter) of the nanofibers was approximately 75. Estimated crystallinity of the cellulose nanofibers was more than 55%. Crystallinity index shows that rutabaga and flax bast fibers had crystallinity similar to that of the control microcrystalline cellulose sample. It is believed that the increase in the crystallinity index is likely to result in stiff and strong fibrils. The average degree of polymerization of cellulose nanofibers is estimated to be about 500.

Investigation of Structure and Distribution of Cellulose Nano-Whiskers in Poly(lactic Acid (PLA) by TEM, SEM, AFM, and X-ray Diffraction

Ingvild Kvien, Ph.D. Student, *Bjoern Steinar Tanem*, Post-Doctoral Fellow, and *Kristiina Oksman*, Professor, Department of Engineering Design & Materials, Norwegian University of Science & Technology, Trondheim, Norway

Growing environmental awareness is leading to extended research on new materials based on natural resources. Nanocomposites, where both the reinforcement as well as the matrix are bio polymers, are now finding applications in medicine, and as coatings and packaging materials. Nano-composites based on cellulose as the nano reinforcement in the thermoplastic poly(lactic acid (PLA) are of particular interest. Cellulose is the most abundant natural polymer on earth, while PLA is made from agricultural raw materials that have good stiffness and strength and can be processed like polyolefins. In this study, the structure of nanocomposites produced by extrusion of PLA and cellulose nano whiskers was investigated. The cellulose nano whiskers used as reinforcement are derived from commercial available microcrystalline cellulose. There are several factors that determine the properties of these nanocomposites, such as size and size distribution of the nano whiskers, as well as the spatial distribution and orientation of the fibers in the matrix material. In addition, physical and chemical bonding between the matrix and the reinforcement are essential. In this work, effort was made to develop and optimize methods and combinations of methods based on different electron microscopy techniques, atomic force microscopy, and x-ray diffraction analysis, to explore in detail the various parameters that determine the properties of this new class of nanocomposites that are based on biodegradable and environmental friendly materials.

Nanostructures and Thermo-Mechanical Properties of 'Green' Nanocomposites from Renewable Cellulosic Plastics

Hwanman Park, Visiting Research Associate, Composite Materials & Structures Center, *Amar K. Mohanty*, Associate Professor, School of Packaging, *Lawrence T. Drzal*, University Distinguished Professor and Director, Composite Materials & Structures Center, and *Manju Misra*, Associate Research Professor, Composite Materials & Structures Center, Michigan State University, East Lansing, Michigan, USA; and *Ellen C. Lee*, Technical Expert, Plastics Research, and *Deborah F. Mielewski*, Technical Expert, Team Leader of Plastics Research, Materials Research & Advanced Engineering Department, Scientific Research Laboratory, Ford Motor Company, Dearborn, Michigan, USA

Sustainable 'green' nanocomposites have been successfully fabricated from renewable cellulose acetate (CA), environmentally benign triethyl citrate (TEC) plasticizer, and organically modified clay. The effects of processing conditions, such as mixing methods, pre-plasticizing times, retention times (RT), clay dispersion in matrix, and addition of compatibilizer maleic anhydride grafted cellulose acetate butyrate (CAB-g-MA) on the performance of these nanocomposites, have been evaluated. The cellulosic plastic with CA/TEC (80/20 or 75/25 wt%) was used as the polymer matrix for nanocomposite fabrication. The nanostructures of these nanocomposites were evaluated through x-ray diffraction (XRD), atomic force microscope (AFM), and transmission electron microscopy (TEM) studies. From all the sequential mixing methods used, powder-powder mixing leads to the most transparent nanocomposites. Cellulosic plastic-based nanocomposites obtained using increased pre-plasticizing times and RT showed better-exfoliated structures. Cellulosic plastic-based nanocomposites with 5 wt% compatibilizer contents showed better-exfoliated structure than the counterpart having 0 or 7.5 wt% compatibilizer contents. The orientation of exfoliated or intercalated clay depends on the location of clay in the nanocomposites. Polygonal shape of exfoliated clay platelets was observed with 500 nm width, and 800 nm length by AFM and TEM imaging. The mechanical properties of the nanocomposites have been correlated with the XRD and TEM observations. It was demonstrated that the mechanical and thermal properties were improved due to good exfoliation and dispersion of clay in the plasticized CA matrix. The 5 wt% compatibilizer loading is optimum for thermo-mechanical improvement. Cellulosic plastic-clay based nanocomposites demonstrate potential for replacing/substituting polypropylene-clay nanocomposites for future 'green' automotive parts.

Mechanical and Thermal Properties of Wood/Layered Silicate/Plastic Composites

Shu-Kai Yeh, Ph.D. Student, Department of Chemical Engineering, West Virginia University, Morgantown, West Virginia, USA; *Daniel Ortiz*, Undergraduate Student, Department of Chemical Engineering, University of Puerto Rico, Mayagüez, Puerto Rico; *Adam Al-Mulla*, Assistant Professor, Department of Chemical Engineering, Kuwait University, Safat, Kuwait; and *Rakesh K. Gupta*, Professor, Department of Chemical Engineering, West Virginia University, Morgantown, West Virginia, USA

Polymer nanocomposites (PNCs) made with layered silicates are known to possess a higher stiffness and a higher heat distortion temperature as compared to the base polymer and also to have flame retardancy and barrier properties. It is, therefore, logical to use PNCs as matrices for wood polymer composites in an effort to enhance the modulus of wood-plastic composites (WPCs). In this study, WPCs were formulated using 50 wt% of 80-mesh maple wood flour (American Wood Fibers maple 8010) and 50 wt% propylene (BP Amoco PP1246)-based PNCs using a Leistritz co-rotating twin-screw extruder. A master batch of polypropylene and nanoclay was employed to first make PNC pellets having different fixed percentages of montmorillonite (clay). These pellets were then compounded with the wood and additives such as antioxidants, lubricants, and coupling agents. The compounded strands emerging from the extruder die were pelletized, dried, and injection molded into a standard ASTM mold using a Battenfield Injection Molding machine. In this manner, molded samples containing a fixed amount of wood and PNC were obtained. The tensile, flexural, and impact properties of these WPCs and also of the base PNCs were measured using an Instron Universal Tester and a BLI impact tester. In addition, the water absorption properties of the WPCs with different levels of layered silicate were studied. It was found that the addition of clay to polypropylene significantly enhanced the Young's modulus of the polymer, and it also resulted in an improvement of the WPC tensile modulus. In particular, the addition of 10

wt% montmorillonite to the polypropylene increased the tensile modulus of the WPC by 10% and the heat distortion temperature by 15°C. These results can be shown to agree with the theoretically calculated tensile moduli of WPCs employing the rule of mixtures.

WEDNESDAY AFTERNOON, MAY 25

WRAP-UP / LUNCHEON SESSION

Opportunities and Challenges for Wood-Plastic Composites in Emerging Product Areas

Michael P. Wolcott, Professor and Research Director, Wood Materials & Engineering Laboratory, Washington State University, Pullman, Washington, USA; *Paul M. Smith*, Professor of Forest Products Marketing, School of Forest Resources, Pennsylvania State University, University Park, Pennsylvania, USA; and *John C. Hermanson*, Research Engineer, USDA Forest Products Laboratory, Madison, Wisconsin, USA

In North America, extruded wood-plastic composites (WPCs) for the building construction industry are a relatively new product whose market growth has been rapid. In 2004, approximately two-thirds of the United States' estimated \$0.9 billion extruded WPC industry production was used in outdoor residential decking and railing structures. However, as technological advances are made, new potential applications continue to emerge. The durable wood structural market, excluding decking and railing, is estimated at nearly \$5 billion annually. Beyond outdoor decking and railing, our research suggests that U.S. builders, wholesalers, and retailers predict the greatest near-term substitution potential of WPCs to be in the following building material applications: window and door frames, siding and accessories, roofing, fencing, and interior moldings. Siding and siding accessories, an estimated \$10 billion market in the U.S. in 2004, has received a great deal of recent attention by WPC product/market development groups. The model posed by fiber-cement siding over the past 10-year period suggests that siding products exhibiting superior value propositions have the potential to capture significant market share. On the industrial side, a demand also exists for strong, cost-effective, durable, and environmentally benign structural and non-structural materials for weather-exposed infrastructure applications. However, industrial product/market development follows a strategy somewhat different from that used in residential decking. On the industrial side, products must be developed with an understanding of engineering requirements. Future potential applications for expanding the current WPC offerings will be discussed while outlining both technical and market needs for development.

POSTER PRESENTATIONS

POSTER 1

Acceptance Criteria for Roofing Composite Materials

Alex Dragomirescu, R&D Manager, and *Jim Nash*, Vice President, Corporate Development, Wellington Polymer Technology Inc., Chatham, Ontario, Canada

The product of Wellington Polymer Technology Inc. (WPTI), identified as Enviroshake®, is a composite roofing material representing an alternative to traditional premium cedar roofing. Wellington Polymer Technology Inc. has been assessed and registered as conforming to ISO 9001:2000. Components used in this product are recycled plastics, recycled rubber, and natural fibers. This presentation covers some of the technical requirements and acceptance criteria for this specific composite product. This type of product cannot be assessed solely on the basis of any existing Canadian standard. Testing for the assessment of Enviroshake® roofing material was conducted at accredited laboratories, in accordance with the following official evaluations: Canadian Construction Materials Centre (CCMC) technical guide; International Code Council (ICC), former International Conference of Building Officials (ICBO) evaluation for special roofing systems; Building Materials Evaluation Commission (BMEC) Ontario authorization report; and State Farm Qualifying Products Listing for premium discounts. The requirements and criteria specified in these documents have been prepared by evaluation officers in consultation with researchers and experts from National Research Council Canada (NRC). The applicable codes and standards taken in consideration were: National Building Code of Canada (NBC) 1995; Canadian General Standards Board (CGSB); American Architectural Manufacturers Association (AAMA); and American Society for

Testing and Materials Limited (ASTM). After a successful evaluation of Envirosake® product, the quality control procedures were reviewed to ensure that consistent product quality can be achieved.

POSTER 2

Carboxymethyl Cellulose Nanocomposites

YongJae Choi, Graduate Student, and *John Simonsen*, Associate Professor, Department of Wood Science & Engineering, Oregon State University, Corvallis, Oregon, USA

Carboxymethyl cellulose films were formed with and without cellulose nanocrystals as fillers. Mechanical properties were improved by the addition of the nano-fillers. Strain-to-break showed unusual, non-classical behavior. Thermal treatment improved the water susceptibility of the composites. The effects of the nanoparticles and the thermal treatments on the composite properties will be discussed.

POSTER 3

DSC and DMA Studies on Poly(vinyl chloride)/Wood Flour Composites

Haihong Jiang, Ph.D. Candidate, and *D. Pascal Kamdem*, Professor, Department of Forestry, Michigan State University, East Lansing, Michigan, USA

Thermal and dynamic mechanical properties of wood-plastic composites (WPC) made of PVC and untreated wood flour and then surface treated, were characterized by using differential scanning calorimetry (DSC) and dynamic mechanical analysis techniques (DMA). Previous studies revealed that the wood surface copper amine treatment can significantly increase mechanical properties of PVC/wood flour composites. DSC studies show that the glass transition temperature (T_g) of WPC made of 60% PVC and 40% treated or untreated wood flour was comparable to that of pure PVC at around $82 \pm 1^\circ\text{C}$. Although it is evident that the influence of wood flour addition as well as wood flour copper amine treatment on the T_g of PVC was negligible, heat capacity differences (ΔC_p) of composites before and after glass transition were dramatically reduced. A two-variable linear model was built to simulate and predict the alteration of ΔC_p in terms of weight percentages of PVC and wood flour as well as their heat capacity differences by introducing a PVC-wood interaction parameter, I_{AB} . The interaction parameter between PVC and copper amine treated wood flour was directly correlated to the copper retentions in wood through a polynomial equation. Extreme conditions in this model associated with PVC alone ($\omega_{PVC}=100\%$) and untreated wood flour ($\text{Cu}\%=0$), were also defined and discussed. T_g of PVC and composites was also determined from the onset temperature of storage modulus (E') curve as well as the peak temperature of $\tan \delta$. The result obtained from DMA study was in agreement with that observed from DSC in respect of T_g . PVC/wood composites exhibited weaker $\tan \delta$ peaks than PVC alone indicating that smaller portions of energy were dissipated for coordinated movements and disentanglements of polymer chains. The rubbery plateaus of E' curves almost disappeared for composites, which was in contrast to a clear plateau range in case of PVC. This suggests that wood flour particles act as "physical cross-linking points" inside the PVC matrix resulting in the absence of the rubbery plateau and high E' above T_g .

POSTER 4

Injection Molded Biocomposites from Natural Fiber and Thermoplastic: Effects of Coupling Agent on Physical Properties

Wanjun Liu, Visiting Research Associate, Composite Materials & Structures Center, *Amar K. Mohanty*, Associate Professor, School of Packaging, and *Lawrence T. Drzal*, University Distinguished Professor, and *Manju Misra*, Associate Research Professor, Composite Materials & Structures Center, Michigan State University, East Lansing, Michigan, USA

Natural fibers such as kenaf, flax, jute, hemp, pineapple leaf fiber, and sisal, have found use as reinforcements in composites in recent years due to their low cost, low density, acceptable specific strength properties, ease of separation, carbon dioxide sequestration and biodegradability. Additionally, these fibers have excellent thermal and sonic insulation properties. It is necessary to add a coupling agent to the system in order to improve the performance of the composites. The coupling agent must exhibit good compatibility with matrix and fiber through chemical or physical interaction. In this study, biocomposites from thermoplastics (soy plastic, polyethylene, and polypropylene)

and natural fibers were produced using a twin-screw extruder and injection molder. The influence of the coupling agent on the physical properties of biocomposites was determined using dynamic mechanical analysis; mechanical properties measurement, Environmental Scanning Electron Microscopy (ESEM) observation, and Fourier transform infrared spectrum characterization. It was found that with the addition of 5 wt% coupling agent (polypropylene grafted malice anhydride), the mechanical strength of hemp fiber reinforced polypropylene biocomposites increased more than 40%. In the kenaf/LDPE and pineapple leaf fiber/soy plastic systems, coupling agents also improved the mechanical properties of the composites. Natural fiber and coupling agent have a nucleation effect in polyolefin-based biocomposites, which brings additional benefits to biocomposite processing and performance. The evidence of an interaction between fiber and coupling agent was found with FTIR and ESEM characterization.

POSTER 5

Lubricant Systems - Improving Wood-Plastic Composite Interaction and Physical Properties

Shelly A. Barnhart, Plastic Applications Chemist, *Don R. Stevenson*, Vice President, R&D, *Michael R. Stevenson*, Technical Director, and *Thomas P. Kelley*, Business Manager, Dover Chemical Corporation, Dover, Ohio, USA

Lubricants are known in the wood-plastic composite (WPC) industry to increase extruder throughput rates, improve surface appearance, and in turn, lower manufacturing cost. It is also known that lubricants can have an adverse effect on physical and mechanical properties and should be used sparingly. The interactions of various lubricant systems, including proprietary lubricant blends from Dover Chemical, were observed in WPCs. Die pressure, temperature, and torque, along with static bending tests, were used to measure interactions. One lubricant blend lowered extruder torque by 20% over the industry standard of 1:1 zinc stearate/EBS. The positive lubrication effects of the product did not have a negative affect on physical properties like the standard or other lubricant systems. In fact, in most cases, the physical properties improved significantly. Tensile strength and flexural modulus were increased by up to 40%. Certain lubricant blends showed positive interactions with WPC by increasing throughput rates by decreasing die pressure, temperature, and torque, and by retaining and improving the physical integrity of the composite.

POSTER 6

Predicting the Elastic Modulus of Natural Fiber-Reinforced Thermoplastics

Angelo G. Facca, Ph.D. Candidate, *Mark T. Kortschot*, Professor, and *Ning Yan*, Assistant Professor, Department of Chemical Engineering & Applied Chemistry, Faculty of Forestry, University of Toronto, Toronto, Ontario, Canada

Natural fiber-reinforced thermoplastics have shown great promise in a variety of applications that were previously dominated by synthetic fiber-reinforced materials. In this study, micromechanical models available in the short fiber composites literature were used to predict the stiffness of some commercially important natural fiber composite formulations. Natural fibers such as hemp, hardwood flour, and rice hulls were blended into high-density polyethylene in mass fractions of 10 to 60 wt%. The stiffness of these composites was compared to composites containing E-glass fibers at similar fiber mass fractions. The experimental data were compared to theoretical trends generated using analytical micromechanics models such as the rule of mixtures, inverse rule of mixtures, Halpin-Tsai, and Cox's shear lag equations. The shapes of the natural fibers were predominately rectangular rather than cylindrical and appropriate Halpin-Tsai and shear lag equations were applied. A modification to Cox's shear lag equation is proposed using the concept of an "equivalent radius" in systems containing rectangular fibers. It was found that the addition of 60 wt% natural fibers to polyethylene could increase its stiffness by 3 to 6 times while increasing its density by a factor of only 1.1 to 1.2. These results were quite well modeled by the appropriate shear lag equations. Shear lag should therefore be useful for predicting the properties of a wide range of formulations, and the success of this approach provides insight into the mechanics of stress transfer between natural fibers and the matrix.

POSTER 7

Properties of Composite Materials Manufactured with Sugar Bagasse Cane Particles and Recycled Plastic (HDPE)

Francisco J. Fuentes T., Associate Professor, Wood Science & Technology, and *José Antonio Silva Guzmán*, Associate Professor, and *Rubén Sanjuán Dueñas* and *Juan Ramos Quirarte*, Professors, Department of Wood, Cellulose & Paper, Universidad de Guadalajara, Zapopan, Jalisco, México

The manufacturing process as well as selected physical and mechanical properties of boards made from bagasse (sugar cane fiber particles) and recycled plastic (HDPE) are discussed in this presentation. Composites boards, 350 x 350 x 5 mm, nominal density 1.0 g/cm³, were made using a flat press process at constant temperature (170°C). The effect of sugar bagasse cane/plastic ratios (40/60, 50/50, 60/40) and pressing times (5, 10, 15 min), on modulus of elasticity, modulus of rupture (MOR), and thickness swelling and water absorption (24 h), were evaluated. Composite boards made with 40/60 (sugar bagasse cane/recycled HDPE plastic), and 5 min pressing time exhibited the best results (MOR 35.1 N/mm², MOE 2883.4 N/mm²), water absorption (5.6%), and thickness swelling (1.7%). According to the results obtained, the combination of sugar cane particles and recycled plastic (HDPE) could be an interesting option for solving both underutilization of sugar production residues and waste plastic materials.

POSTER 8

WPCs Made from Modified Wood

Kristoffer Segerholm, Ph.D. Student, KTH Building Materials, Royal Institute of Technology, Stockholm, Sweden; *Magnus E.P. Wälinder*, Assistant Professor, KTH Building Materials, Royal Institute of Technology, Stockholm, Sweden, and Head of Materials & Products Group, SP Trätekt, Swedish National Testing & Research Institute, Wood Technology, Stockholm, Sweden; and *Mats Westin*, Research Scientist, SP Trätekt, Swedish National Testing & Research Institute, Wood Technology, Stockholm, Sweden

Recent environmentally related restrictions regarding the use of preservative-treated wood support the need for development of new eco-efficient materials. This poster presents the initial development of new biomaterial-based wood-polymer composites (WPCs) designed with high outdoor durability. The main composite components consist of different types of modified wood particles and cellulose ester thermoplastics (i.e. a fully bionderived WPC). The concepts for wood modification are based on furfurylation, acetylation, heat treatment, and enzymatic modification routes. Background information as well as material science aspects and results from initial durability trials are presented.

POSTER 9

WPCs Made from Modified Wood - Estimation of Wood-Polymer and Wood-Water Interaction Parameters

Lars Elof Bryne, Ph.D. Student, and *O. Söderström*, Professor, KTH Building Materials, Royal Institute of Technology, Stockholm, Sweden; *Magnus E.P. Wälinder*, Assistant Professor, KTH Building Materials, Royal Institute of Technology, Stockholm, Sweden, and Head of Materials & Products Group, SP Trätekt, Swedish National Testing & Research Institute, Wood Technology, Stockholm, Sweden; *Mats Westin*, Research Scientist, SP Trätekt, Swedish National Testing & Research Institute, Wood Technology, Stockholm, Sweden; and *Kristoffer Segerholm*, Ph.D. Student, KTH Building Materials, Royal Institute of Technology, Stockholm, Sweden

Methodologies for experimental and modeling studies of wood-polymer and wood-water interactions and interfacial properties are being developed. The goal is to assess the efficiency of wood modification routes based on heat treatment, furfurylation, and acetylation on the wood-polymer adhesion and interfacial properties in WPCs. This work basically involves physico-chemical characterization of unmodified and modified wood strands (i.e. wetting characterization by the Wilhelmy plate technique and surface chemical composition by Fourier transform infrared (FTIR) spectroscopy). Based on these experiments, so-called wood-polymer and wood-water interaction parameters will be modeled.

POSTER 10

Woodflour/Linseed Oil Resin Composites

Mirna Mosiewicki, Ph.D. Student, *Mirta I. Aranguren*, Professor, and *Julio Borrajo Fernandez*, Professor, INTEMA - Facultad de Ingeniería, University Nacional Mar del Plata, Mar del Plata, Argentina

The purpose of this work has been to formulate and study new composites using fillers and resins obtained from renewable resources combining low-cost and good mechanical properties. Two examples will be presented: 1) a composite made from a polyester-type resin crosslinked with styrene and reinforced with pine woodflour, and 2) a reinforced rigid polyurethane foam made from hydroxylated linseed oil and MDI prepolymer with the addition of woodflour. The relationship between filler content, porosity fractions, and mechanical properties of materials prepared from the linseed oil resin/styrene copolymers and woodflour was investigated. The foams were tested to evaluate density, thermal conductivity, and compression behavior. An unsaturated polyester-like resin was obtained by functionalizing the oil triglyceride molecules in two basic steps: glycerolysis to produce a monoglyceride and then reaction with maleic anhydride to produce a maleinated monoglyceride. The product is further blended with styrene, the reactive comonomer, and cured via a free radical polymerization to produce a rigid crosslinked thermosetting polymer. Composites were manufactured using dried pine woodflour and the copolymerization of a polyester type resin with styrene in a 60:40 weight proportion. The resin was synthesized from a commercial linseed oil supplied by Grainer S.A. All the woodflour particles passed through the mesh 100 (U.S. standard) and were retained by the sieve 200. Composite materials were prepared by varying filler contents from 0 to 60% by weight with respect to total composite weight. Dynamic mechanical analysis and static three-point bending were performed on the samples. The addition of the rigid filler increases the storage modulus of the composite, mainly in the rubber phase. As the content of woodflour increases, the $\tan \delta$ peak of the composites appears at higher temperatures compared with the curve of the pure matrix. Increasing addition of filler also facilitates the appearance of voids in the sample, so that above 30% wt of woodflour the mechanical properties of the samples fall below expected values. The problem could be partially remediated by using higher pressures during processing (heated press mould). Rigid PU foams were also produced from hydroxylated linseed oil. The formulation considered the use of a slight excess of MDI isocyanate as in the standard formulations, where the commercial polyalcohol was completely replaced by the linseed oil-derivate. The final product showed a regular distribution of cells, and a density between 35 and 45 kg/m³. The foams will be filled with 5-20% wt of woodflour. The addition of this reinforcement has been already proved with standard foams, and it also be tried on linseed oil foams. The work will include the determination of thermal conductivity and compression properties of the foamed samples.

POSTER 11

Industrial Infrastructure Markets for Woodfiber-Plastic Composites

Daniel F. McGraw, Graduate Research Assistant, and *Paul M. Smith*, Professor of Forest Products Marketing, School of Forest Resources, Pennsylvania State University, University Park, Pennsylvania, USA

In response to consumer demands for low maintenance and durable timber construction and increased environmental regulation of preservative-treated lumber, the wood-plastic composite (WPC) industry has emerged in the last decade. Currently valued at nearly \$1 billion (retail USD), the natural-fiber polymer composite industry has primarily focused on residential products such as exterior decking, railing, doors, and windows. However, the industry has the potential to expand into a host of new products, including structural components for housing, marine, and transportation infrastructure applications. This research investigates the use, selection, and distribution of industrial infrastructure materials used in short span (HS20 and below) bridges. Decision makers and influencers, including engineers in State and Federal Government Agencies, private architecture and engineering firms, and others in the golf course and trail bridge construction industries, are surveyed via personal interviews and mail and internet surveys. Research constructs include: 1) bridge decking material attribute importance/satisfaction; 2) factors influencing the material purchase/selection decision; 3) benefits of new product and/or material adoption; and 4) use of distribution channels and communications mix elements. This key industrial infrastructure market information will pro-

vide insight into material use and substitution opportunities in these structural applications.

POSTER 12

Biodegradability of Bio-Flour-Filled Biodegradable Polymer Bio-Composites in Natural and Composted Soil

Han-Seung Yang, Post-Doctoral Research Associate, Wood Materials & Engineering Laboratory, Washington State University, Pullman, Washington, USA; and *Hyun-Joong Kim*, Associate Professor, *Hee-Soo Kim*, Ph.D. Student, and *Seung-Woo Choi*, M.S. Student, Laboratory of Adhesion & Bio-Composites, Department of Forest Products, Seoul National University, Seoul, South Korea

In this study, the biodegradability of bio-flour-filled polybutylene succinate (PBS) bio-composite was performed under natural and simulated municipal solid waste (MSW) aerobic composted soil. PBS is a biodegradable polymer, made from the polycondensation reaction of glycols and dicarboxylic acid, and is naturally degraded by microorganisms in soil. We evaluated the biodegradability of bio-flour-filled PBS bio-composites according to the content and filler particle size of bio-flour. As the bio-flour loading and filler particle size was increased, the biodegradability of the bio-composites increased. The percentage weight loss and the reduction of mechanical properties of rice-husk flour (RHF, 200 mesh) filled PBS bio-composites in the composted soil burial test were significantly greater than those in the natural soil burial test. This result was confirmed by SEM morphology micrographs of the degradation surface for bio-composites and FTIR-ATR analysis. These results indicate that these bio-composites may be able to reduce environmental problems associated with waste pollution and can support the bioproduct development of bio-composites as "green-composites" or eco-friendly materials.

POSTER 13

Thermal Stability and Thermal Expansion of Lignocellulosic Material-Filled Polyolefin Bio-Composites

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

In the TGA analysis of bio-composites, their thermal stability was found to slightly decrease and the ash content increase as the lignocellulosic filler loading was increased. This is a logical consequence of the lower thermal stability of the lignocellulosic filler compared to that of the matrix polymer. The dispersion and interfacial adhesion between the lignocellulosic filler and thermoplastic polymer were important factors affecting the thermal stability of the composite system. In order to improve their compatibility and interfacial adhesion, the incorporation of a compatibilizing agent into the lignocellulosic material-thermoplastic polymer composites is recommended. In the TMA analysis, the thermal expansion of the composites was found to decrease with increasing filler loading and increasing compatibilizing agent content. Lignocellulosic filler is a suitable material for preventing the thermal expansion of composite materials caused by atmospheric changes.

POSTER 14

Viscoelastic and Thermal Analysis of Lignocellulosic Material-Filled Polyolefin Bio-Composites

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

In the DMTA analysis of bio-composites, their rigidity was found to increase as the lignocellulosic filler loading increased due to the rigid lignocellulosic filler. The compatibilizing agent incorporated bio-composite showed the highest storage modulus among these composites due to strong interfacial adhesion. The maleated polypropylene (MAPP) incorporated bio-composite showed slightly higher storage modulus than the maleated polyethylene (MAPE) incorporated composite, but MAPE is suitable for polyethylene composites due to its

stiffening effect. In the DSC analysis, the glass transition temperature of the composites was found to increase with increasing filler loading because the lignocellulosic filler works as impurities in the thermoplastic polymer matrix. The glass transition temperature of the 3 wt% compatibilizing agent incorporated 30 wt% filler-PP composite was lower than that composite without any compatibilizing agent. The polymer chain is able to start librating easily with the well bonded filler, but the chain may not be able to start easily if the filler is not well bonded because the dispersed fillers in the polymer matrix obstruct chain libration.

POSTER 15

A Method for Studying of the Wood-Plastic Interaction. Part I: Mechanical Interlocking

William Gacitua E., Graduate Research Assistant and Ph.D. Student, and *Michael P. Wolcott*, Professor and Research Director, Wood Materials & Engineering Laboratory, Washington State University, Pullman, Washington, USA

Using a vacuum bagging process and scanning electron microscopy (SEM), the mechanical interlocking between samples from various wood species from small-diameter logs and high-density polyethylene (HDPE), without coupling agent and additives, were studied. The vacuum and pressure at high temperatures help melting and flowing of the HDPE mainly through the radial face (tangential direction) in small softwood samples, generating a clear interlocking in uncoupling systems. There is an important effect of the wood species and flow direction on the thermoplastic movement in cell lumens. The position from where wood samples of small logs were taken is another factor that resulted in different HDPE interlocking after the vacuum bagging process. It was found that anatomical features of softwoods play a fundamental role in this interaction. This is explained due to a difference between wood species in terms of type and amount of pits. The vacuum bagging cycle used was found to be a good method to compare the physical interaction of a thermoplastic with different wood species.

POSTER 16

Interfacial and Nondestructive Evaluation of Natural Fiber Composites by Micromechanical and Acoustic Emission Technique

Tran Quang Son, Graduate Student, and *Joung-Man Park*, Professor, School of Advanced Materials Science & Engineering, Engineering Research Institute, Gyeongsang National University, Chinju, South Korea; and *Byungsun Hwang*, Director, Materials Processing, Composite Materials Group, Korea Institute of Machinery & Materials, Changwon, South Korea

Interfacial shear strength (IFSS) of environmentally friendly natural fiber-reinforced polymer composites play a very important role in controlling the overall mechanical properties. In this work, the IFSS of kenaf and Ramie fibers/epoxy systems were evaluated using a combination of the micromechanical technique and the microdroplet test to determine optimal conditions. The clamping effect on fiber elongation was determined as well. In addition, the mechanical properties of the natural fibers were investigated using a single fiber tensile test and analyzed statistically by both uni- and bimodal Weibull distributions. Microfailure modes of different natural fiber structures were observed using an optical microscope.

POSTER 17

Performance of New Lubricants and Coupling Agents in WPCs

Joe B. Williams, Global Technical Service Team Leader, Lonza Inc., Williamsport, Pennsylvania, USA; *Lei Rao*, Global Technical Service Researcher, Lonza Inc., Allendale, New Jersey, USA; and *Bob Skillen*, Process Technology Staff Member, Lonza Inc., Williamsport, Pennsylvania, USA

Performance characteristics of two new lubricants with several commercial coupling agents in both pine and oak wood-polymer composites have been determined. The new lubricants significantly reduced the extruder torque and improved the appearance of extruded profiles compared to formulations containing just coupling agent. Combinations of lubricants and coupling agents were found that allowed good extrusion characteristics and profile appearance. The physical properties of these profiles were considerably better than formulations containing no coupling agent.

POSTER 18

Effect of Enhanced Anhydride Copolymer Coupling Agents in Injection Molded Wood-Flour-Filled Polyethylene Composites

David M. Dean, Senior Research Engineer, *Anthony M. Angelo*, Technical Assistant, and *Andrew Smillie*, Research Manager, DuPont Packaging & Industrial Polymers, Wilmington, Delaware, USA

Over the past several years, the ability of maleic anhydride grafted polymers to improve the physical properties of wood-polymer composites has been confirmed by a number of research groups. These maleic anhydride grafted polymers, typically containing 0.5 to 1.5 weight percent maleic anhydride, act as a coupling agent by binding the wood fillers to the polymer matrix through a chemical reaction of the maleic anhydride functional group with the surface of the wood. In this study, we report on next generation coupling agents based on high molecular weight, random copolymers of ethylene, and anhydride functional monomers that have been specifically designed for wood-polymer applications. Flexural strength, modulus, and impact strength of wood-polymer formulations using standard maleic anhydride grafted polymers as coupling agents will be compared to materials that incorporate the new ethylene/anhydride copolymers. The focus of the presentation will be on injection molding formulations, but information pertinent to materials designed for extrusion processing will also be discussed.

POSTER 19

Fiber-Reinforced Polypropylene Composites from Small-Diameter Southern Pine Trees

Suzhou Yin, Visiting Scientist, *Siqun Wang*, Assistant Professor, and *Timothy G. Rials*, Professor and Director, Forest Products Center, and *Kevin M. Kit*, Assistant Professor, and *Marion Hansen*, Professor, Department of Materials Science & Engineering, University of Tennessee, Knoxville, Tennessee, USA

The Southeast U.S. is faced with an increasingly severe threat of catastrophic wildlife due to higher and higher fuel loads on both public and private land. Certainly, there are technological hurdles that must be overcome to make small-diameter timber more economically attractive. Considerable research and development has focused in recent years on composites from wood and synthetic plastics. This effort has successfully introduced new products into high-value markets not traditionally held by wood, but has only looked at wood flour in plastic extrusion process technology. Attractive options exist that may take advantage of the unique characteristics of the woodfiber (rather than comminuted particles) by combining them with plastic in conventional panel pressing methods. This presentation focuses on a new process development to manufacture fiber-reinforced plastic composites using whole exploded wood biomass of small-diameter beetle-killed southern pine trees; and reports on properties of fiber-reinforced polypropylene composites.

POSTER 20

Thickness Swelling Rate of Wood-Polymer Composites

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The objective of this study was to investigate the effect of polymer content and board density on the hygroscopic thickness swelling rate of dry-processed woodfiber/polymer composites. A swelling model developed by Shi and Gardner was used to study the thickness swelling process of woodfiber/polymer composites exposed to water vapor conditions in which a parameter, K , was used for the comparison of the swelling rate. The polymer materials used to process the wood/polymer composites were from the reclaimed automobile plastic mixture, also called polymer fluff. Polymeric diphenylmethane diisocyanate (pMDI) resin was used as a binder. Six polymer contents (0, 15, 30, 45, 60, and 100%) and four target board densities (0.55, 0.75, 0.90, and 1.00 g/cm³) were investigated in the experiments. Board density had a significant effect on the swelling rate of the composites. The swelling rate also increased linearly as a function of a decrease in board density. Polymer fluff content had no effect on the swelling rate.

POSTER 21

Composites with Agave Fiber and Polypropylene: Mechanical and Physical Properties

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The objective of this study was to obtain composites with agave fiber and polypropylene and to characterize the physical and mechanical properties of these composites. Composites were prepared by two compounding technologies: 1) thermokinetic mixing and 2) extrusion compounding using a twin-screw extruder. Composites were obtained over a range of compositions, and the effects of the addition of maleated polypropylene (MAPP) as coupling agent on the properties of the composites was observed. The mechanical properties of tensile modulus, tensile strength, flexural modulus, flexural strength, and izod impact strength were measured on injection-molded specimens. The topics covered in this poster presentation are: 1) the effects of fiber content, 2) the effects of fiber length, and 3) the effects of the coupling agent (MAPP) on the mechanical properties of strength and modulus. The effects of moisture sorption at 65 and 90% relative humidity were also evaluated. Fractured surfaces were investigated by scanning electron microscopy (SEM) to reveal the effects of coupling agent on the interface between the agave fiber surface and the polypropylene matrix. The addition of MAPP coupling agent had a marked effect on improving the tensile, flexural, and unnotched izod impact strength, and MAPP also decreased the moisture absorption of the composites. In composites without MAPP, only the tensile and flexural moduli increased as the content of agave fiber increased because of the inherently greater stiffness (rigidity) of the agave fiber compared to polypropylene. Because agave tequilana is a plant of great value in México, its use in composites with polypropylene is recommended with the addition of MAPP coupling agent. Additional recommended research in this area is the investigation of recycled polypropylene as the composite matrix.

POSTER 22

Characterization of Wood Cell Walls Using X-ray Diffraction/Scattering Techniques

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The mechanical properties of wood are a function of the nanostructure of its cell wall. In particular, the tilt angle of the cellulose fibrils with respect to the longitudinal cell axis (microfibril angle) plays a major role in wood mechanics. For analysis of these hierarchical structures, it is critical to use position-resolved diffraction methods. Extremely powerful approaches are scanning x-ray diffraction and scanning small-angle x-ray scattering. These non-destructive techniques allow the characterization of the fiber orientation (texture) as well as the size and the arrangement of the constituents in the nanocomposite. By applying both methods it is possible to simultaneously obtain information on several hierarchical levels. The diffraction/scattering experiment yields information on the subnanometer and nanometer level, while the scanning procedure visualizes the specimen with a resolution corresponding to the x-ray beam diameter, which is in the micrometer range. This contribution reviews some recent experiments carried out with the goal to explain the relation between structure and mechanical function in wood.

POSTER 23

The Effects of Material Parameters on the Diffusion and Sorption Properties of Polypropylene - Wood Flour Composites

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Composites of wood in a thermoplastic matrix are considered a low-maintenance solution to using wood in outdoor applications. Although service life of wood-plastic composites is critical, the water transport properties of these composites have not been fully explored. Our

objective in this investigation was to determine how material parameters affect the moisture transport properties of injection-molded polypropylene-filled with pine wood flour. A two-level, full factorial design was used to investigate the effects of wood content, wood flour particle size, coupling agent, and surface removal. Unfilled polypropylene specimens were also investigated and compared to the composites. Sorption experiments were performed at different relative humidities as well as in water. A DIN standard laboratory method was modified to investigate moisture diffusion at several humidities. Thin specimens were used to seal desiccant in a moisture-proof container. Increases in weight over time were then used to determine moisture diffusion rates at a given humidity. Diffusion-coefficients were calculated according to Fick's Laws.



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