

BIOGRAPHIES & ABSTRACTS

9th International Conference on

WOOD & BIOFIBER PLASTIC Composites

May 21-23, 2007

Monona Terrace Community & Convention Center
Madison, Wisconsin, USA

The conference is hosted by the USDA Forest Service, Forest Products Laboratory and Forest Products Society. In cooperation with the Canadian Natural Composites Council, IUFRO Composites & Reconstituted Products Division, Luleå University of Technology, University of Tennessee's Forest Products Center, and University of Toronto's Faculty of Forestry and Centre for Biocomposites & Biomaterials Processing.

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Conference Chair

*Craig M. Clemons
Materials Research Engineer
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Dr. Craig M. Clemons is a Materials Research Engineer in the Engineered Composite Sciences Group at the USDA Forest Products Laboratory (FPL) in Madison, Wisconsin. He received a B.S. in Chemical Engineering, an M.S. in Forestry, and a Ph.D. in Materials Science from the University of Wisconsin-Madison. For the past 17 years, he has worked at FPL developing composite materials from plastics, additives, and fillers/reinforcements derived from wood or other natural fibers. His areas of interest lay both in the materials science and processing of these composites.

Proceedings Editor

*Nicole M. Stark
Chemical Engineer
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Madison, Wisconsin, USA*



Dr. Nicole M. 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, Dr. Stark 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-Madison, and a Ph.D. in Forest Science from Michigan Technological University.

Committee Members and Session Moderators

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



Dr. John J. Balatinecz received a B.S. in Forestry from the University of British Columbia, an M.S. from the University of Washington, and a Ph.D. in Wood Science from the University of Toronto. He served as Professor of Wood Science & Forest Products in the Faculty of Forestry, University of Toronto from 1966 to 1998. His main research interests include material science, with a focus on natural fiber composites, and recycling of wood, paper, and plastics. Since 1990, with colleagues from the University of Toronto, he has been one of the key organizers of bi-annual international conferences on Woodfiber-Plastic Composites in Toronto. Recently, with assistance from the University of Toronto's Office of Development, Dr. Balatinecz spearheaded a successful campaign to raise major funding for the first endowed chair in Wood Science in the Faculty of Forestry. In addition, he raised funds for five endowed scholarships. In 2002, Dr. Balatinecz was awarded an Honorary Doctoral degree from the University of West Hungary, the same institution where he began his academic career 53 years ago as a student.

*Christoph Burgstaller
Researcher
Transfer Center for Polymer
Technology
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Wels, Austria*



Dr. Christoph Burgstaller is a Researcher at the Transfer Center for Polymer Technology, Upper Austrian Research, working in the field of wood and natural fiber-reinforced composites. He received a degree from the Technical University of Linz, Austria, in the Study of Technical Chemistry – Diploma thesis was on fiber-reinforced composite materials with melamine resins. His Ph.D. thesis was on investigations on the relationships between wood particle size, wood type, and content on the mechanical and physical properties of wood-plastic composites.

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



Dr. David P. Harper is an Assistant Professor at the Tennessee Forest Products Center, University of Tennessee, Knoxville, Tennessee. His research interests include wood/polymer interfaces, fuels and chemicals from lignocellulosics, 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 C. Hermanson is a Research Engineer 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 & 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-Madison.

*Rebecca E. Ibach
Research Chemist
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Dr. Rebecca E. Ibach is a Research Chemist in the Lignocellulosic Materials & Surface Science Project at the USDA Forest Products Laboratory in Madison, Wisconsin. Her research is in chemical modification and property enhancement of wood-based and bio-fiber resources to improve properties and to maximize end-use performance of advanced bio-based composites. Her research involves developing an understanding of the chemical reactions taking place in biological, thermal, UV, and moisture degradation of wood and wood-based composites. With this information, the development of new methods of modifying wood to protect against biological attack, improved dimensional stability, improved UV resistance, and thermal stability based on environmentally friendly technologies can be developed to attain long-term durability of bio-based composite materials. Previously, she was a Research Chemist, Modified Lignocellulosic Materials Project; Research Chemist, Wood Preservation & Fire Research; Chemist, Wood Preservation Project; and Chemist, Analytical Chemistry Project at the USDA Forest Products Laboratory. She received a B.S. from St. Norbert College (DePere, Wisconsin), and a Ph.D. from the University of Wisconsin-Madison.

*Carol Lewis
Executive Vice President
Forest Products Society
Madison, Wisconsin, USA*



Carol Lewis is the Executive Vice President of the Forest Products Society, Madison, Wisconsin. Ms. Lewis has more than 15 years experience in the field of education and in not-for-profit organization management. She began her professional career as Assistant Plant Manager/Office Manager with Mould-Rite, Inc. in Pekin, Indiana, a producer of fine hardwood flooring and moldings. In 1996, she joined the staff of Koetter Woodworking in Borden, Indiana and served as Project Coordinator for all facets of the design and development of The Forest Discovery Center in Starlight, Indiana. From 1997 to 2002, Ms. Lewis served as both the Executive Director of The Forest Discovery Center and the Executive Director of the Starlight Visitor's Association. In October of 2002, she left southern Indiana to join the staff of the National Hardwood Lumber Association (NHLA) in Memphis, Tennessee as Associate Executive Manager. During her tenure with NHLA, she was responsible for oversight of the operation

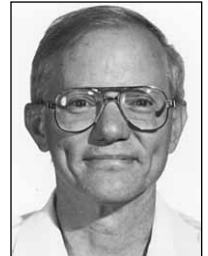
of the 14-week NHLA Inspection School and for coordination and implementation of all NHLA educational programs.

*Kristiina Oksman
Professor
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Dr. Kristiina Oksman is a Professor and Chair on Wood & Bionanocomposites at the Division of Manufacturing & Design of Wood & Bionanocomposites, Luleå University of Technology (LTU), Skellefteå, Sweden. She has been active in natural fiber composites work for 15 years, working on mechanical properties, characterization, and processing of composites based on renewable materials. She received an M.S. in Materials Science & Engineering and a Ph.D. from Luleå University of Technology. After a period as Project Leader at the Swedish Institute of Composites, she has been Professor of Polymers & Polymer Based Composites at the Norwegian University of Science & Technology in Norway until she was appointed as Chair and Professor at LTU in 2006.

*Roger M. Rowell
Pioneering Scientist
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Dr. Roger M. Rowell is a Pioneering Scientist at the USDA Forest Products Laboratory in Madison, Wisconsin. He is also a Professor in the Department of Biological Systems Engineering 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; National Science Foundation Exchange Professor at the Wood Research Institute, Kyoto University; and 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.

*Philippe Tingaut
Post-Doctoral Research Associate
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Dr. Philippe Tingaut is a Post-Doctoral Research Associate in the Tennessee Forest Products Center, University of Tennessee, Knoxville, Tennessee.

Jerrold E. Winandy
Project Leader
USDA Forest Service
Forest Products Laboratory
Madison, Wisconsin, USA



Dr. Jerrold E. Winandy is Project Leader of the Engineered Composites Science research work unit at the USDA Forest Products Laboratory (FPL) in Madison, Wisconsin. The research work unit is responsible for developing new and improved composites from wood and other nonwood fiber sources using thermoset, thermoplastic, inorganic, and other naturally-derived binders. He is personally active in enhancing the durability and service-life of wood- and bio-based composites. In 2004, Dr. Winandy was elected a Fellow in the International Academy of Wood Science. He serves as Adjunct Professor in the Department of Bio-Based Products & Biosystems Engineering at the University of Minnesota and the Department of Forest Products at Mississippi State University. He is also an Honorary Fellow in the Department of Biological Systems Engineering at the University of Wisconsin-Madison. He received a B.S. and M.S. from Purdue University and a Ph.D. from Oregon State University. He has served as Chair of technical subcommittees in American Society for Testing & Materials (ASTM), American Wood Preservers' Association (AWPA), and the International Union of Forest Research Organizations (IUFRO). He was General Chair of the AWPA Technical Committees from 1999-2002. His personal research has historically dealt primarily with the modeling effects of chemical, thermal, and biological agents on the engineering properties on wood and wood composites.

Session Speakers and Poster Presenters

Ramesh-Babu Adusumalli
Ph.D. Student
Department of Materials Science & Process Engineering
BOKU-University of Natural Resources
& Applied Life Sciences
Vienna, Austria

Ramesh-Babu Adusumalli is a Ph.D. Student in the Department of Materials Science & Process Engineering, BOKU-University of Natural Resources & Applied Life Sciences, Vienna, Austria. His Ph.D. thesis is on cellulose fiber-reinforced composites and is funded by Kompetenzzentrum Holz GmbH, Austria. He received a Pre-University Certificate from the Intermediate Education in A.G. Government Junior College, India; Bachelor in Chemical Engineering from CBIT College, Osmania University, India; and an M.S. in Bio-Based Materials from Fachhochschule Reutlingen, Germany.

Stanley I. Aghedo
Graduate Student and Research Assistant
Department of Chemical Engineering
Queen's University
Kingston, Ontario, Canada

Stanley I. Aghedo is a Graduate Student and Research Assistant in the Department of Chemical Engineering, Queen's University, Kingston, Ontario, Canada. His research interests include characterization of plant fibers; characterization of interface in plant fiber-reinforced polymer; suitable processing method of plant fiber-reinforced polymer composites; and characterization of plant fiber composites and durability effects. Previously, he was an Engineer, The Ken Associates, Nigeria; and Engineer, Sogalson Nigeria Ltd., Nigeria. He received a Bachelor of Engineering in Civil Engineering from the University of Benin, Nigeria.

Ayse Alemdar
Post-Doctoral Researcher
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Dr. Ayse Alemdar is a Post-Doctoral Researcher in the Centre for Biocomposites & Biomaterials Processing, University of Toronto, Toronto, Ontario, Canada. Her research interests include cellulose nanofiber composites. Previously, she was an Assistant Professor, Istanbul Technical University, Turkey; and Post-Doctoral Fellow, Joseph Fourier University, France. She received a B.S., M.S., and Ph.D. from Istanbul Technical University.

Mikael Ankerfors
Research Assistant
STFI-Packforsk AB
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Mikael Ankerfors is a Research Assistant at STFI-Packforsk AB in Stockholm, Sweden. STFI-Packforsk AB is one of the world's leading R&D companies in the fields of pulp, paper, graphic media, packaging and logistics. The activities range from basic research to direct commission, where our expert skills and know-how are utilized to find solutions for customers to apply in their operations. All research is focused on customer value.

Fred M. Ascherl
Technical Support Manager
Rio Tinto Minerals
Centennial, Colorado, USA

Fred M. Ascherl is the Technical Support Manager, Rio Tinto Minerals, Centennial, Colorado, USA. Rio Tinto Minerals (formerly Borax, Luzenac, and Dampier Salt) is the acknowledged world leader in developing industrial minerals – building blocks for life, and for products that contribute to better living and in developing solutions to build their customers' businesses. Borates are the key ingredients in hundreds of products, essential to plants, and part of a healthy diet for people. Borate-treated wood has been used successfully for more than 60 years in New Zealand, and for more than a decade in Hawaii and elsewhere in the U.S. Borogard® ZB has been used commercially in wood composites since 1992 and in wood-plastic composites (WPC) since 2000, and is the leading additive providing affordable, effective, durable, and safe broad spectrum protection for WPCs. Luzenac talc has been shown to enhance the performance of WPCs by increasing MOE and MOR, reducing moisture absorption and by improving processing efficiency.

María L. Auad
Assistant Professor
Department of Polymer & Fiber Engineering
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Dr. María L. Auad is an Assistant Professor in the Department of Polymer & Fiber Engineering, Auburn University, Auburn, Alabama. Her research interests include polymer material science, polymer nanocomposites, flow behavior of polymers, control of microstructures and nanostructure in materials, and polymers for structural and biomedical applications. Previously, she was a Research Associate, University of Southern California; and Research Assistant, California Institute of Technology. She received a B.S. in Chemical Engineering and Ph.D. in Materials Science from the University of Mar del Plata, Argentina.

Dilpreet S. Bajwa
Manager, R&D
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Fayetteville, Arkansas, USA

Dr. Dilpreet S. Bajwa is Manager of R&D at Greenland Composites, Fayetteville, Arkansas. Previously, he was Director of R&D, EPOCH Composite Products Inc.; Senior Product Development Engineer, International Paper Company; and Research Scientist, Masonite International Corporation. He graduated from the University of Illinois in 2000 with a Ph.D. in Wood Science & Engineering. His research experience involved product development, analysis, and testing of wood and natural fiber-plastic composites. He has published numerous peer-reviewed papers and articles on wood-plastic composites.

Nathan J. Bechle
Research Assistant
Department of Civil & Environmental Engineering
University of Wisconsin
Madison, Wisconsin, USA

Nathan J. Bechle is currently an undergraduate Research Assistant in the Department of Civil & Environmental Engineering, University of Wisconsin-Madison, working at the USDA Forest Products Laboratory. The project he has been an assistant on for the past year and a half has been the modeling of the viscoelastic properties of wood-plastic composites (WPC). He designs and conducts innovative, custom statistical experiments using computational mechanics to both control the hardware as well as analyze the results. Currently, he is assisting in the assembly and implementation of a pneumatically controlled, 3-year creep study of WPCs. Previously, he was a Fluid Mechanics Teaching Assistant and Structures & Materials Testing Laboratory Technician, University of Wisconsin-Madison. He received a B.S. from the University of Wisconsin-Madison.

Evandro Bittencourt
Professor, Materials & Management Science
Research Coordination of Management Department
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Dr. Evandro Bittencourt is a Professor of Materials & Management Science in the Research Coordination of Management Department, University of the Region of Joinville, Joinville, Brazil. He is also a Professor of Mechanics & Production Systems at Santa Catarina State University, Joinville, Brazil. He received a B.S. in Civil Engineering from Santa Catarina State University; Post-Graduate in Management Science and Post-Graduate in Mathematics from the University of the Region of Joinville; M.S. in Materials Science & Processes, Santa Catarina State University; and Ph.D. in Materials & Engineering Science, Santa Catarina Federal University.

Nico C. Bordeanu
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Dr. Nico C. Bordeanu is a Post-Doctoral Scientist and Project Leader in the Wood Laboratory, Swiss Federal Laboratories for Materials Testing & Research (EMPA), Dübendorf, Switzerland. His research interests include isolation and characterization of cellulose fibrils, chemical modification of cellulose fibrils, synthesis of cellulose fibrils reinforced adhesives (particularly 1 component polyurethane), and chemical analytic of wood adhesives. Previously, he was a Research Fellow and Ph.D. Student, University of Saarland, Germany. He received an M.S. in Chemistry and Ph.D. from the University of Saarland.

Jianmin Chen
Post-Doctoral Research Associate
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Orono, Maine, USA

Dr. Jianmin Chen is a Post-Doctoral Research Associate in the Advanced Engineered Wood Composites Center, University of Maine, Orono, Maine. Dr. Chen's responsibilities include conducting research on wood-plastic composite development: develop formulas of advanced product with high demanding properties; characterized the static and dynamic mechanical properties of advanced wood-plastic composites, which focused on Tg analysis, creep, long-term creep prediction through master curve, aging effect; synthesized standard reliability test procedures and summarized general reports for DMTA, DSC, TGA tests; and conducting DOE and properties evaluation on client samples. Dr. Chen received a B.S. in Textile Engineering from Qingdao University (China); M.S. in Textile Material Engineering from Northwest Textile Institute (joint graduate program with Shandong Textile Engineering Institute) (China); Ph.D. in Textile Materials Engineering from Donghua University (former China Textile University) (China); and Ph.D. in Integrated Textile & Apparel Science from Auburn University.

Qingzheng Cheng
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Qingzheng Cheng is a Ph.D. Candidate and Research Assistant in the Tennessee Forest Products Center, University of Tennessee, Knoxville, Tennessee. He is majoring in Natural Resources, working under the advisement of Dr. Siqun Wang and Dr. Timothy G. Rials. He conducts fundamental research in the isolation of cellulosic fibrils at micro and nano scales by both mechanical and chemical methods from woody fiber resources, the characterization of cellulosic fibrils, and bio-based nanocomposites. Previously, he was a Graduate Research Assistant, University of Maine; Research Assistant and Assistant Professor, Chinese Academy of Forestry; Graduate Research Assistant, Northeast Forestry University; and Technician, Furniture Factory of Yishui County (China). He received a Bachelor of Engineering and Master of Engineering from Northeast Forestry University, and an M.S. from the University of Maine.

Carlos A. Correa
Associate Professor
Laboratório de Blendas e Compósitos Termoplásticos
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Dr. Carlos A. Correa is an Associate Professor in the Postgraduate Program in Materials Engineering & Science at the Universidade São Francisco, Itatiba, 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, Nitroflex Petrochemical S.A. He received a Bachelor in Materials Engineering and an M.S. from the Federal University of São Carlos, Brazil; and a Ph.D. in Advanced Materials from Cranfield University, U.K.

Li Dagang
Professor and Director
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Dr. Li Dagang is a Professor and Director of the Department of Packaging Engineering, Nanjing Forestry University, Nanjing, P.R. China. His research interests include wood anatomy, wood drying, wood mechanics, and wood-plastic composites. He is a member of the Vice Council, Academy of Wood Science Society of China; and Commissioner and Vice General Secretary, Specialist Committee of Wood-Plastic Composites of China. He is also a Visiting Professor, Kyoto University, Japan. Previously, he was an Associate Professor

and Lecturer, Nanjing Forestry University. He received an M.S. and Ph.D. in Wood Science & Technology from Nanjing Forestry University, and Ph.D. in Wood Science & Technology from Northeast Forestry University.

Alex Dragomirescu
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Alex Dragomirescu is R&D Manager at Wellington Polymer Technology Inc., Chatham, Ontario, Canada. He is a highly experienced Research Engineer having a successful career in Product Development of Polymer Materials with applications in plastics, composites, rubber, and specialty polymers industry. His responsibilities include generating proposals for improving product performance by keeping abreast of intellectual property and competitors, possessing the ability to define problems, establish facts, and draw valid conclusions; coordinates overall R&D activity with a recognized stability and success in managing projects, products, and people; hands on familiarity with continuous manufacturing processes by identifying and correcting materials problems affecting quality, yield, and cost; conducts statistical analysis for tracking, trending, and forecasting performance; and solves problems in applied sciences with creativity and innovative spirit by employing well developed analytical abilities, investigation, and organizational skills, providing high-quality conceptual work. Previously, he was a Research Assistant, University of Western Ontario; Senior Research Engineer, Polymer Additives, Research Institute for Petroleum Processing & Petrochemical; and Scientist Engineer, Plastics, Central Institute for Chemical Research. He received a B.S. in Chemical Engineering from the University Oil & Gas, Romania; and an M.S. in Chemical Engineering from the University of Western Ontario, Canada.

Yicheng Du
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Yicheng Du is a Graduate Research Assistant in the Department of Forest Products, Mississippi State University, Starkville, Mississippi. His research toward a Ph.D. in Forest Products is focused on design, fabrication, and evaluations of natural fibers-reinforced plastic composites for structural applications. He received an M.S. in Forest Products from Nanjing Forestry University in 2004. Since 2006, he has been at Mississippi State University.

Keith J. Effertz
Project Manager
Aspen Research Corporation
White Bear Lake, Minnesota, USA

Keith J. Effertz is a Senior Development Engineer, Consulting Group Leader, and a Project Manager of the Aspen Research Corporation, a wholly owned subsidiary of the Andersen Corporation. Mr. Effertz began his career with Aspen in 1997 as an Engineer in the Materials Science area. He subsequently joined the Wood Technology group in 1997 and moved to Aspen Materials, a compounding facility within Aspen that specialized in composite materials and product development in 2001. Prior to joining Aspen, he worked briefly with the Composite Materials Technology Center in Winona. Since joining Aspen, he has assumed responsibility for many projects that are directly related to the composite material, Fibrex®, and the development of improved compounding and manufacturing processes. For example, he has been involved in defining moisture relationships of wood-fiber composites, new product method development, and is currently working on the improvements of the Fibrex® family of materials. Mr. Effertz has contributed his expertise in the use of Designed Experiments, Six Sigma tools, and compounding development such as batch to continuous, direct, and reactive type compounding/extrusion. He has been instrumental in helping Aspen attain their ISO 9001:2000 certification. He holds a Bachelor of Engineering in Composite Materials, which he received from Winona State University in 1997.

Karl Englund
Associate in Research, Wood-Plastic Composites
Wood Materials & Engineering Laboratory
Washington State University
Pullman, Washington, USA

Dr. Karl Englund is an Associate in Research, Wood-Plastic Composites in the Wood Materials & Engineering Laboratory, Washington State University, Pullman, Washington. Previously, he was a Post-Doctoral Research Associate and Graduate Research Assistant, Washington State University; Research Technician, West Virginia University; and Plant Technical Director and Quality Control Supervisor, Trus Joist MacMillan. 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.

Markus Euring
Ph.D. Student and Scientific Assistant
Institute for Forestbotany
Georg-August University of Goettingen
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Markus Euring is a Ph.D. Student and Scientific Assistant at the Institute for Forestbotany, Georg-August University of Goettingen, Goettingen, Germany. He received a B.S. and M.S. from the Technical University of Munich (TUM), Germany.

Omar Faruk
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Dr. Omar Faruk completed his B.Sc. (Hons) and M.Sc. in Chemistry at the University of Chittagong (Bangladesh). With a DAAD (German Academic Exchange Service) scholarship, he moved to the Institute for Materials Science, Polymer & Recycling Technology, Department of Mechanical Engineering, University of Kassel, Germany in 1999 to work on the research project "Natural Fiber and Wood Reinforced Composites". After completion of the scholarship (2001), he continued to work there as a Research Assistant to pursue his Ph.D. In 2005, he received his Ph.D. in Engineering and until February 2006, he worked there as a Post-Doctoral Researcher. He joined the Department of Forestry, Michigan State University, East Lansing, Michigan, as a Visiting Research Associate in March 2006. He has approximately 50 publications (including a book) to his credits, which have been published in different international journals and at conferences.

Shelly R. Fox
Scientist
Rohm & Haas
Charlotte, North Carolina, USA

Shelly R. Fox is a Scientist at Rohm & Haas in Charlotte, North Carolina. She joined Rohm & Haas Company's Technical Service group in 1998 to work on the development of formulations for architectural gloss, primer, and stain applications. Her recent work has been focused on coatings for wood-plastic composite substrates and understanding the changing decking market. She received a B.S. in Biology from the University of North Carolina at Wilmington.

William Gacitua E.
Ph.D. Candidate, Civil & Environmental Engineering
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Wood Materials & Engineering Laboratory
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William Gacitua E. is a Research Assistant in the Wood Materials & Engineering Laboratory at Washington State University (WSU), where he is working on a Ph.D. in Civil & Environmental Engineering. His responsibilities include investigating the influence of wood morpholo-

gy on properties of thermoplastic wood composites. He received a B.S. in Civil & Wood Engineering and an M.S. in Wood Science & Technology from Bio-Bio University (Chile).

Piedad F. Gañán

Professor

*Department of Polymer Materials & Polymer Processing
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Dr. Piedad F. Gañán is a Professor in the Department of Polymer Materials & Polymer Processing, Universidad Pontificia Bolivariana, Medellín, Colombia. Today, vegetable sources as agricultural residues can be used to develop recyclable or biodegradable materials with high performance. Dr. Gañán is leading several research projects using Colombian Musaceas residues to develop high strength cellulose composites and nanocomposites. Previously, he was a Visiting Professor, Royal Institute of Technology (KTH); Visiting Research Engineer, Gaiker; and Research Engineer, Universidad Pontificia Bolivariana. He received a Chemical Engineer degree from Universidad Pontificia Bolivariana, a Bachelor from UNAD (Spain), and a Ph.D. from Basque Country University (Spain).

Douglas J. Gardner

Professor of Wood Science & Technology

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Dr. Douglas J. Gardner is a Professor of Wood Science & Technology in the Advanced Engineered Wood Composites Center, University of Maine, Orono, Maine. Previously, he was an Associate Professor of Wood Science & Technology, University of Maine; Associate Professor, Michigan Technological University; Associate Professor of Forestry, West Virginia University; and Post-Doctoral Research Associate, Auburn University. His research interests include polymer science, surface chemistry, and adhesion and adhesives. He is President of the Society of Wood Science & Technology, and a member of the Adhesion Society, American Chemical Society, and Forest Products Society. 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 & Engineering*. He is an Honorary Member of the Union of Wood Processing Manufacturers of the Slovak Republic. He received a B.S. in Forestry and a Certificate of Advanced Study in Pulp & Paper Management from the University of Maine, and a Ph.D. in Wood Science & Technology from Mississippi State University.

Marek Gnatowski

Technical Director

Polymer Engineering Co. Ltd.

Burnaby, British Columbia, Canada

Dr. Marek Gnatowski is Technical Director of Polymer Engineering Co. Ltd., Burnaby, British Columbia, Canada. He has 36 years of experience in industrial consulting, process control, and research and development including 25 years experience in North America in fields related to polymeric materials and wood. This includes over 10 years work with wood-plastic composites. He is the author of three book chapters in *Plastics Waste Management*, 10 papers in scientific journals, 13 conference presentations, 11 patents and has 3 patent applications pending. Dr. Gnatowski has held the position of Technical Director of Polymer Engineering Co. Ltd. for over 20 years. The main focus of his research activities has been the response of natural and synthetic materials to environmental exposure.

Neil R. Granlund

R&D Engineer

ALTERFORM (A Division of Phillips Plastics Corp.)

Prescott, Wisconsin, USA

Neil R. Granlund is an R&D Engineer at ALTERFORM (A Division of Phillips Plastics Corporation) in Prescott, Wisconsin. He is responsible for the research and development of additives for wood polymer composites including antimicrobial and foaming additives. Previously, he was a Lab Technician, 3M. He received a B.S. in Chemistry from the University of Minnesota-Minneapolis.

Warren J. Grigsby

Senior Scientist

Biomaterials Engineering Group

Scion

Rotorua, New Zealand

Dr. Warren J. Grigsby is a Senior Scientist in the Biomaterials Engineering Group at Scion, Rotorua, New Zealand. He has been employed with Scion (formerly 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. Previously, he was a Post-Doctoral Researcher, Monash University (Australia); and Post-Doctoral Researcher, University of California-Davis. He received a B.Sc., M.Sc., and Ph.D. from the University of Waikato (New Zealand).

Joseph E. Jakes

Graduate Student and Researcher in Training

USDA Forest Service

Forest Products Laboratory

Madison, Wisconsin, USA

Joseph E. Jakes is a Researcher in Training at the USDA Forest Products Laboratory and a Graduate Student at the University of Wisconsin-Madison pursuing his Ph.D. The majority of his research involves developing methods for nanoindentation in the areas of wood adhesives, chemical modifications of wood, and wood-plastic composites. Previously, he was a Physical Science Technician, USDA Forest Products Laboratory. He received a B.S. in Chemical Engineering and M.S. in Materials Science from the University of Wisconsin-Madison.

Adam R. Jaszkiwicz

Scientific Staff – Dipl.-Ing. and Ph.D. Student

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Dr. Jong Nam Lee is a Research Scientist in the Sustainable Engineered Materials Institute, Virginia Tech, Blacksburg, Virginia. His responsibilities include the development of a simulation model to optimize steam explosion process and the manufacturing process of wood fiber-thermoplastic composites. Previously, he was a Post-Doctoral Researcher, Louisiana State University; Graduate Research Assistant, Auburn University; and Production Supervisor of MDF, Foresco (South Korea). He received a B.S. from Seoul National University, an M.S. from North Carolina State University, and a Ph.D. from Auburn University.

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Dr. Geoff Pritchard is an independent consultant working for Hackwell Group and also for Smithers Rapra, part of the U.S. based Smithers Group. He graduated from the University of St. Andrews (Scotland) in 1961 with a Bachelor in Chemistry, and became interested in polymers while working at the Central Research Laboratories of the Dunlop Company in Birmingham, England, on the synthesis of elastomers. Later, he earned a Ph.D. from the University of Aston with a thesis on the physical changes taking place during thermosetting resin crosslinking. For 28 years, he was at Kingston Polytechnic/University in London, England, researching the durability of reinforced plastics, especially in relation to their defense applications. He was Head of the Department of Chemistry for several years until 1995. Recently, Dr. Pritchard has moved into market studies and has authored reports on fillers, PVC, polymer additives, and wood-plastic composites as well as editing a series of books on reinforced plastics. He is editor of the research journal *Polymers & Polymer Composites* and has been Chair of the program committee for the Addcon World series of technical conferences on polymer additives for the past 11 years.

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Dr. Scott Rennekar is an Assistant Professor in the Department of Wood Science & Forest Products, Virginia Tech, Blacksburg, Virginia. He works in the area of wood and bio-based composites. His background is in wood science with an emphasis on polymer chemistry. Dr. Rennekar received a Ph.D. from Virginia Tech. Prior to joining the department, he studied at the University of California-Berkeley for his M.S. degree. Dr. Rennekar's research program revolves around how macromolecular interactions/interfaces dictate performance of composite materials. From this broad theme, his interests are two-fold: combining nanotechnology into contemporary wood-based composites and creating bio-based composites from the bottom-up (controlled placement of nanoscale building blocks). His long-term research goal is to create a wood-like material from any source of biomass to be

used within the wood composites industry. Dr. Rennekar teaches Wood Adhesion and Composites II and co-instructs Wood Materials Science and Technology.

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Christopher E. Richards is a Mechanical Engineer at Aspen Research Corporation, White Bear Lake, Minnesota. His responsibilities include project manager and consulting support for the development of new materials, processes, and designs. He is particularly involved in material development, processing, and testing for internal development, parent company, and third-party customers. Previously, he was an Intern for Aspen Materials (material processing and development), Aspen Research Corporation. He received a B.S. in Mechanical Engineering from the University of Minnesota-Minneapolis.

Christopher D. Risbrudt
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Since being named Director of the USDA Forest Service's Forest Products Laboratory (FPL) in September, 2001, Dr. Christopher D. Risbrudt has focused the laboratory's attention on forest health and the wise use of wood and wood products. He has directed FPL's attention to five broad future-oriented areas: 1) Developing the forest biorefinery; 2) Nanotechnology; 3) Advanced housing systems and concepts; 4) Improved engineered wood products and composites; and 5) Use of wood in non-residential construction. To ensure the maximum benefit from FPL's research, Dr. Risbrudt has also encouraged increased communications and technology-transfer activities. 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. He 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 & 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 & Resource Assessment in 2001, and later that year, Acting Deputy Chief, Programs & 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 in Forest Administration and a Ph.D. in Forest Economics.

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In 1988, Dr. Mohini Sain received a Ph.D. in Chemical Engineering from the Technical University, Bratislava. Prior to joining the Pulp & Paper Research Centre at the Université du Québec à Trois-Rivières (1994), he worked in the polymer industry. In 1999, he joined the Department of Chemical Engineering, University of New Brunswick. Currently, he is Director of the Centre for Biocomposites & Biomaterials Processing, and Professor in the Faculty of Forestry, and is cross-appointed to the Department of Chemical Engineering & Applied Chemistry, University of Toronto. Dr. Sain specializes in paper sizing, coating chemistry, recycling, and biocomposite and nano-biocomposite manufacturing. He received an Industry-University NSERC Synergy Award in 2001 for his work in heavy metal scavenging.

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Dr. Victoria Scarborough is the Director of New Technology for the Diversified Brands Division of the Sherwin Williams Company. She has worked as the Director of R&D on the Thompson's® Water Seal® brand of products for the last 25 years. She holds numerous domestic and international patents for the development of water-based water repellent coating technologies and is a member of the FSC, ASTM, AWWA, and Forest Products Society.

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SESSION ABSTRACTS

MONDAY MORNING, MAY 21

OPENING PLENARY SESSION

Market and Product Opportunities for WPCs/NFPCs Beyond Building Industry

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The area of bio-fiber and industrial biomaterials research has seen a phenomenal surge of interest, particularly with regard to its comparable properties to conventional man-made fibers in various composite applications. Though stringent environmental legislation and consumer awareness has been instrumental to support an approach of long-term sustainable growth of bio-fiber composites, industries in North America have not been able to capitalize on the full potential of bio-fiber applications beyond the building and decking sectors. There exists a number of opportunities to expand existing markets and develop new products for bio-based composites. Some of the new possibilities for future development are: structural composites – furniture, load bearing walls, roof systems, sub-flooring, stairs, framing components; non-structural and semi-structural composites – automotive interior parts, doors, windows, furniture, gaskets, ceiling tiles, molding; mold-able products from geo-textiles – food industry containers, sea-going containers for commodity goods, pallets; hybrid products – new products by combining different natural/synthetic materials. Out of these novel applications, the automotive sector has experienced a tremendous growth, especially in interior applications. The European automotive industry has already taken the lead and currently uses around 20,000 metric tons of natural plant fibers in low-stress applications in luxury cars. The growth for bio-fibers in automotive components in EU is expected to increase by 54% per year. During the last decade, bio-fiber reinforced polymer composites have been used by European car makers for door panels, seat backs, headliners, package trays, dashboards, and trunk liners. Legislations in the United States and Europe have issued a specific directive on end-of-life vehicles, which has accelerated the process of switching to recyclable and biodegradable constituents. This legislation promotes the use of environmentally safe products and reduces the landfills. The directive predetermines the landfill fraction of a vehicle to 15% for the year 2005, and then gradually reduces it to 5% for the year 2015. This paper will present an overview on the market growth and product development opportunity beyond outdoor building applications.

Applications for WPCs in Europe

Geoff Pritchard, Technical Consultant, Hackwell Group, Worcester, United Kingdom; and **Brian Hackwell**, Commercial Consultant, Hackwell Group, Tunbridge Wells, United Kingdom

The market for wood-plastic composites (WPC) in Europe is still emerging. The materials have been used there for many years, chiefly in the car industry, but sales of other WPC products have been low until recently. Although the largest single outlet remains the automotive sector, end uses in construction, infrastructure, and furniture are becoming more important. Strenuous efforts are being made by manu-

facturers to develop new WPC products, including some for indoor use, to compensate for the absence of a large European decking market. The WPC employed in construction and infrastructure often uses higher wood contents than those used in the U.S.; virgin polypropylene is the preferred resin, but HDPE and PVC are also used. The recent entry of larger manufacturers into the business is likely to accelerate growth by providing much-needed investment and publicity. Several smaller suppliers nevertheless have low production levels. A number of distribution channels for WPC are now being developed.

The Quandary of Composite Decking for the Coatings Manufacturer

Victoria Scarborough, Director of New Technology, Diversified Brands Division, Sherwin Williams, Cleveland, Ohio, USA

Wood-plastic composite (WPC) decking is marketed as nearly maintenance-free. Most first-time consumers have strongly latched on to this assertion. However, gathering evidence indicates that there are more weaknesses in these products than first claimed. Some types of cleaning/coating applications can enhance the performance of WPCs and contribute to better performance. The channel for selling both WPC decking and most coatings is through the big box stores like Home Depot, Lowes, Menards, and others. While they sell both types of products, they continue to advocate the low maintenance aspects of WPC. Thus, the coatings manufacturer is caught with trying to sell a product that will provide performance benefits to WPCs and a buyer who thinks WPCs are not needed for protection. This presentation addresses some of these issues and discusses the future of coatings for WPCs.

MONDAY AFTERNOON, MAY 21

CONCURRENT SESSIONS

SESSION IA: Nanocomposites

Mechanical and Morphological Characterization of Cellulose Fibrils and their Composites

Tanja A. Zimmermann Schütz, Senior Scientist, **Evelyn Pöhler**, (former) Scientist, and **Nico C. Bordeanu**, Post-Doctoral Scientist and Project Leader, Wood Laboratory, Swiss Federal Laboratories for Materials Testing & Research (EMPA), Dübendorf, Switzerland

Cellulose fibrils with diameters below 100 nanometer and lengths in the micrometer range were mechanically isolated out of various raw materials like wheat straw, sulphite pulp, or cellulose powder. The morphology of the obtained fibrils or fibril networks was characterized by electron microscopy. Homogeneous, translucent films with hydroxypropyl cellulose and different portions of fibrils extracted from the different raw materials were prepared and mechanically tested. The strength, stiffness, and hardness of the fibril-reinforced HPC films were determined by tensile testing and nanoindentation. The fibril alignment in the composite films was analyzed by transmission electron microscopy (TEM) and atomic force microscopy (AFM). The results from the mechanical tests can be associated with the results obtained from the morphological characterizations. A significant increase in the mechanical properties is derived for the films with fibril contents of 10 wt% compared to the films with lower fibril portions. As a network formation can only be observed for composites with a fibril portion of at least 10 wt%, the existence of fibril networks has been found to be of great importance for the mechanical properties of the HPC composites.

On the Manufacture and Uses of Nanocellulose

Mikael Ankerfors, Research Assistant, and **Tom S.C. Lindström**, Senior Research Manager, STFI-Packforsk AB, Stockholm, Sweden

Turbak and co-workers first manufactured microfibrillar cellulose (MFC) many years ago. The process was never commercialized, largely because of high energy consumption and clogging problems when delaminating fibers in high-pressure homogenizers. Some years ago, there was a renewed interest in the process following the development of nanocomposites at Toyota. Research scientists at STFI-Packforsk, in a joint venture with KTH/HUT, also took on the challenge. After the millennium, MFC was renamed to nanocellulose to be distinguished from cellulose whiskers (shorter strands of cellulose microfibrils) and microcrystalline cellulose (hydrolyzed to leveling off Dp, followed by homogenization) The manufacturing procedures will be discussed as well as properties and potential uses of nanocellulose.

Process and Properties of Bio-Nanocomposites Based on Cellulose Whiskers

Aji P. Mathew, Assistant Professor, and **Kristiina Oksman**, Professor, Division of Manufacturing & Design of Wood & Bio-Nanocomposites, Luleå University of Technology, Skellefteå, Sweden

Inspired by the growing environmental awareness by all, there is a deliberate interest in finding new materials that are biodegradable and environmental friendly. Therefore, materials derived from natural resources are now studied extensively. Preparation of novel bio-nanocomposites based on biopolymers has drawn specific attention. It is expected that these types of nanocomposites will open new areas for medical, packaging, and electronic applications. This presentation will deal with a novel processing technology of bio-nanocomposites based on cellulose whiskers and different biopolymers. Processing techniques for nanostructured materials includes drying, feeding, and blending techniques. Characterization of the structure of nanocomposites will also be presented. Nanowhisker dispersion and size in the matrix polymer has shown to be difficult to characterize since both the matrix and reinforcement are soft, non-conductive, and light materials. Cellulose nanowhiskers isolated from wooden source, by acid hydrolysis, have a size about 5 nm in width and 200-300 nm in length. These whiskers were blended with polylactic acid (PLA) and cellulose acetate butyrate (CAB) by melt compounding to achieve bio-nanocomposites. The composites mechanical and thermal properties as well as the nanostructure of cellulose whiskers and composites will be presented.

Temperature Induced Shape Memory Behavior of Nanocellulose Composites

María L. Auad, Assistant Professor, Department of Polymer & Fiber Engineering, Auburn University, Auburn, Alabama, USA; **Vasili Contos**, Graduate Student, and **Steven Nutt**, Professor of Materials Science, School of Engineering, and Director, Center for Composites Research, University of Southern California, Los Angeles, California, USA; and **N.E. Marcovich**, Associate Professor, and **Mirta I. Aranguren**, Professor, Department of Chemical Engineering, INTEMA, Universidad Nacional de Mar del Plata, Mar del Plata, Argentina

Smart polymeric materials capable of “remembering” their original shape after having been deformed and later undergoing application of an external stimulus are called shape memory polymers (SMPs). We are interested in segmented polyurethane (PU) based materials with shape memory behavior. The reinforcement of SMPs using nanofillers, is a new approach of enhancing the performance of these materials. The incorporation of these fillers into SMPs can produce performance enhancements (particularly elastic modulus) at small nanoparticle loadings (~1-5 wt%). The addition of nanofillers allows production of stiffer materials and yet with deformation capacity comparable to that of the unfilled polymer and enhanced recovery force. In this work, the use of cellulose nanocrystals was investigated. They were prepared by acidolysis of microcrystalline cellulose and redispersed in an organic solvent to be used as nanoreinforcement of segmented PU. The presence of the nanocrystals induces a more clear separation of soft and hard segments, as indicated by DSC and x-ray measurements. Remarkably, the modulus of the films was significantly increased (~70%) by the addition of cellulose at concentrations as low as 0.5, 1% by weight. Tensile cycling of the films under cycled temperatures allowed the investigation of the shape memory response of these cellulose nanocomposites. The response was highly repeatable after the second cycle with shape recovery on the order of 80%.

Reinforcement Capability of Wheat Straw Fibers from Micro to Nano-Size

Ayse Alemdar, Post-Doctoral Researcher, and **Mahya Mokhtari** and **Jaymini Kamat**, Research Assistants, Centre for Biocomposites & Biomaterials Processing, University of Toronto, Toronto, Ontario, Canada; **Kristiina Oksman**, Professor, Division of Manufacturing & Design of Wood & Bio-Nanocomposites, Luleå University of Technology, Skellefteå, Sweden; and **Mohini Sain**, Professor and Director, Centre for Biocomposites & Biomaterials Processing, Faculty of Forestry, University of Toronto, Toronto, Ontario, Canada

We have manufactured wheat straw reinforced composites with improved mechanical and thermal properties. Microfibers were obtained by soda pulping wheat straw and nano-size microfibrils were obtained by defibrillation of this pulped wheat straw. The morphology and thermal properties of both fiber types were determined to show their suitability as reinforcements. The applied soda pulping increased

the fibers' cellulose content from 38 to 82% due to hydrolysis of the hemicelluloses and lignin from the straw walls. Transmission electron microscopy results showed that the defibrillation process of the pulped fibers increased their fibrillation degree, resulting in improved mechanical and thermal properties of composites constructed from these fibers. TEM images showed that the diameters of the wheat straw fibers were decreased from micro to nano-size by the defibrillation process. Thermogravimetric analysis showed the pulping and defibrillation processes dramatically increased the thermal properties of the wheat straw fibers. The composites were produced using, respectively, the microfibrils and nano-size microfibrils as reinforcement, with polyvinyl alcohol as the matrix in both cases. This was done by immersing a thin mat of micro/nano-size fibers in a dilute PVA solution. The morphology of the composites was investigated by scanning electron microscopy. The Young's modulus and tensile strength of composites were compared with those of pure PVA and found to be considerably improved.

Optically Transparent Composites Reinforced with Cellulose Nanofibers

Hiroyuki Yano, Professor, **Shin-ichirou Iwamoto**, Ph.D. Student, and **Shinsuke Ifuku** and **Antonio Norio Nakagaito**, Post-Doctoral Fellows, Laboratory of Active Bio-Based Composite, Research Institute for Sustainable Humanosphere, Kyoto University, Uji, Kyoto, Japan; **Masaya Nogi** and **Kentaro Abe**, Post-Doctoral Fellows, International Innovation Center, Kyoto University, Nishikyoku-ku, Kyoto, Japan; and **Keishin Handa**, Project Leader, Mitsubishi Chemical Group Science & Technology Research Center, Mitsubishi Chemical Corporation, Yokohama, Kanagawa, Japan

We report on the first example of a transparent composite reinforced with bacterial cellulose nanofibers. The composite is optically transparent at a fiber content as high as 70%, with low thermal expansion coefficient (similar to that of silicon crystal), and mechanical strength five times that of engineered plastics. These significant improvements in thermal and mechanical characteristics of the composite are due to the web-like network of semi-crystalline extended chains of nanofibers, produced by the bacterium *Acetobacter xylinum* (*Glucronobacter aceti*). The nanofiber-network reinforced polymer composite maintains its transparency, it is light, flexible, and easy to mold, thus making it an excellent candidate for a variety of applications such as substrate for flexible displays, components for precision optical devices, and windows for automobiles or trains, among others.

SESSION IB: Processing and Performance

Effect of Nano-Clay on Foaming of Wood Fiber/PP/Clay Composites

Y.H. Lee, Ph.D. Student, Faculty of Engineering, **Takashi Kuboki**, Post-Doctoral Fellow, and **Chul B. Park**, Professor and Director, Microcellular Plastics Manufacturing Laboratory, Department of Mechanical & Industrial Engineering, and **Mohini Sain**, Professor and Director, Centre for Biocomposites & Biomaterials Processing, Faculty of Forestry, University of Toronto, Toronto, Ontario, Canada

This paper investigates the foaming behavior of wood fiber/polypropylene (PP)/nano-clay nanocomposites. The nanocomposites with small amount of clay were prepared and the structures of nanocomposites were characterized by XRD and TEM. The extrusion foaming experiment blown with N₂ was conducted. The cell nucleation and growth of composite foams were studied with processing parameters such as temperature and pressure and clay content. The effect of nano-clay on the final cell morphologies and foam density of wood fiber/PP/clay nanocomposite foams were identified.

Characterization of the Morphological and Mechanical Properties of Foamed WPCs

Neil R. Granlund, R&D Engineer, ALTERFORM (A Division of Phillips Plastics Corporation), Prescott, Wisconsin, USA

The utilization of blowing agents is being actively pursued by a number of WPC companies to reduce the weight and cost of their products. However, many of the blowing agents on the market have not offered a strong value proposition to WPC producers. Additionally, questions regarding the deleterious effects that foaming has on the mechanical properties of WPCs is of concern. We are investigating whether there is a significant correlation between foam WPC microstructure and mechanical properties and will report our findings here.

Injection Molded Solid and Microcellular Polylactide Compounded with Recycled Paper Shopping Bag Fibers

Adam J. Kramschuster, Research Assistant, Department of Mechanical Engineering, University of Wisconsin, Madison, Wisconsin, USA; **Shaoqin (Sarah) Gong**, Assistant Professor, Department of Mechanical Engineering, University of Wisconsin, Milwaukee, Wisconsin, USA; **Alexander Chandra**, Graduate Student, Department of Mechanical Engineering, University of Wisconsin, Madison, Wisconsin, USA; **Srikanth Pilla**, Graduate Student, Department of Mechanical Engineering, University of Wisconsin, Milwaukee, Wisconsin, USA; and **Lih-Sheng Turng**, Associate Professor and Co-Director, Polymer Engineering Center, Department of Mechanical Engineering, University of Wisconsin, Madison, Wisconsin, USA

Two types of recycled paper shopping bag fibers were melt-compounded using a twin-screw extruder with bio-based/biodegradable polylactide (PLA) at 10- and 30-wt%. To study the effects of a coupling agent on the mechanical properties of the PLA/fiber composites, composites at the same fiber loading levels with and without silane were prepared. These PLA/fiber composites were then injection molded to produce both solid and microcellular tensile bars. The mechanical properties of these composites were tested and the cell morphology of the microcellular samples was examined using scanning electron microscopy. The specific mechanical properties of these composites are reported as well as the cell density and average cell size for the microcellular samples. In particular, the effects of adding fibers with or without silane and at different loading levels on the mechanical properties of PLA as well as the cell morphology of the microcellular PLA will be discussed.

Effect of Mixing Conditions During Composite Processing on the Morphology of the Natural Fibers

Carlos J. Quijano-Solis, Ph.D. Student, and **Ning Yan**, Assistant Professor, Faculty of Forestry, University of Toronto, Toronto, Ontario, Canada; and **S.Y. (Tony) Zhang**, Senior Scientist and Group Leader, Forintek Canada Corporation, Ste-Foy, Québec, Canada

During the processing of natural fiber composites, fibers, polymers and additives are usually blended in mixers prior to being extruded or molded into the final product form. However, the mixing equipment will typically exert such high elongational and shear forces on the fibers and polymers that fiber breakage can occur. Fiber breakage will result in a reduction in fiber length, diameter, and aspect ratio and thus alter their distributions. The reduction in aspect ratio is undesirable since a minimum aspect ratio is needed to obtain satisfactory product performance. Larger aspect ratios will more effectively transfer load from the matrix to the fiber and provide higher reinforcement to the composites. Fiber breakage is well known to be a major concern for the very rigid synthetic fibers due to their high stiffness. But, natural fibers, even though more flexible, have also shown to break in the mixer during the manufacturing of natural fiber composites. Little is known as to how fiber pre-process morphology and characteristics affect the degree of breakage. Therefore, in this study we measured the pre- and post-process morphology of a wide range of natural fibers as a function of mixing conditions. Fibers of different flexibility, coarseness, length, diameter, and length distribution are blended with polypropylene as matrix polymer in an internal mixer at different process conditions. A range of fiber mass fractions is included in the study. Fiber morphological properties are obtained using a combination of experimental techniques including FQA and solvent extraction. The results on the relationship among fiber breakage, fiber characteristics, and mixing conditions are discussed and presented.

Processing of WPCs – Influence of Temperature and Shear

Christoph Burgstaller and **Wolfgang Stadlbauer**, Researchers, Transfer Center for Polymer Technology, Upper Austrian Research, Wels, Austria

In this work, we investigated the influence of shear and temperature on the processing and the properties of wood-plastic composites (WPC). Different formulations with wood contents ranging from 30 to 70 wt% wood in polypropylene were produced via extrusion or compounding and injection molding, respectively. The samples were subjected to different testing methods (i.e. mechanical testing and color measurements). Further, an extraction step for regaining the wood particles from the composites has been carried out. Subsequently, fiber geometry measurements were carried out. The influence of shear and temperature was correlated to the properties of the WPCs as well as trends were shown for the relations between fiber damage and processing step and wood content.

Extrusion Rate Influences on the Mechanical and Physical Properties of WPCs

Karl Englund and **Brent Olson**, Associates in Research, Wood-Plastic Composites, Wood Materials & Engineering Laboratory, Washington State University, Pullman, Washington, USA

The rate of extruding wood-plastic composites (WPC) can have a significant influence on the appearance, mechanical, and physical properties of the final product. As extrusion technologies develop and the WPC decking market becomes more commodity-based, higher production rates continue to entice industry. In the following study, HDPE and PP-based WPCs were extruded on a commercial counter-rotating conical twin-screw extruder at varying screw rates and temperature profiles. The solid 1x5.5" WPCs were then tested for flexure performance, water sorption behavior, and oxidation induction time (OIT).

TUESDAY MORNING, MAY 22

CONCURRENT SESSIONS

SESSION IIA: Materials and Morphology

Flexural Moduli of Vapor-Grown Carbon Nanofiber/Wood Flour/Polypropylene Composites

Jun Li Shi, Post-Doctoral Associate, and **Jilei Zhang**, Associate Professor, Department of Forest Products, **Hossein Toghiani**, Associate Professor, Department of Chemical Engineering, **Charles U. Pittman, Jr.**, Professor, Department of Chemistry, and **Yibin (Anna) Xue**, Assistant Research Professor, Center for Advanced Vehicular Systems, Mississippi State University, Starkville, Mississippi, USA

Vapor-grown carbon nanofibers (CNF) (60-250 nm diameter, micron length) were compounded into polypropylene (PP) and wood flour (WF) matrices at the loading percentages of 1, 2, and 5% (by wt% of PP), respectively. High shear blending in a Brabender at 190°C was employed. The blended samples were ground to granules and hot-press molded at 1.02 MPa and 190°C. The flexural modulus of the resulting composites was obtained by four-point bending test and the values were compared. Incorporation of CNFs increased the moduli of these nanocomposites substantially. For example, PP/20%WF composites exhibited flexural moduli 2273 MPa versus 3098 MPa for PP/20%WF/5%CNF. This indicates the use of small amounts of CNFs as reinforcing filler enhances PP/wood composite stiffness.

Hybrid HDPE/Wood-Flour/Montmorillonite Nanocomposites

Omar Faruk, Visiting Research Associate, and **Laurent M. Matuana**, Associate Professor, Department of Forestry, Michigan State University, East Lansing, Michigan, USA

The effects of compounding methods and nanoclay types on the mechanical, morphology, and rheological properties of HDPE/wood-flour/montmorillonite nanocomposites were studied. Various blending methods, including dry and melt blending in one or multiple steps were examined. The experimental results indicate that the extent of property improvement and dispersion of nanoparticles in the nanocomposites is strongly influenced by the blending approach and type of nanoclay used during processing.

X-ray Microtomography of Fracture Surfaces in Wood Fiber-Reinforced Polypropylene

Mark T. Kortschot, Professor, Associate Chair, and Undergraduate Coordinator, and **B. Cheng**, Undergraduate Student, Department of Chemical Engineering & Applied Chemistry, University of Toronto, Toronto, Ontario, Canada

It is well known that the impact strength of wood fiber-reinforced polypropylene (WFRP) is a function of the mechanisms of fiber pull-out and breakage associated with crack growth. In this study, x-ray microtomography has been used to produce a detailed three-dimensional image of the fracture surface of a WFRP. A single horizontal slice from the tomograph, parallel to the mean fracture surface, but located just below it, is presented. Sockets corresponding to wood fibers pulled out by the other half of the specimen are clearly visible in this slice. The mean fracture path can be computed by fitting a surface of limited flexibility through points within the matrix corresponding to a density of 50%. From this surface, the elevation of protruding fibers and the depth of the sockets can be measured to produce a pre-

cise measure of roughness that correlates to composite toughness. The effect of fiber morphology and surface treatment on fracture surface morphology and the corresponding impact strength will be discussed.

Electron-Beam Curable Additives for WPCs

David P. Harper, Assistant Professor, **Timothy G. Rials**, Professor and Director, and **George Dorsey**, Consulting Research Scientist, Tennessee Forest Products Center, University of Tennessee, Knoxville, Tennessee, USA; **William L. Griffith**, Research Staff Member, Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA; and **Karl Englund**, Associate in Research, Wood-Plastic Composites, and **Michael P. Wolcott**, Professor, Composite Materials Engineering/Adhesion and Research Director, Wood Materials & Engineering Laboratory, Washington State University, Pullman, Washington, USA

Efficacy of metal acrylates and methacrylates as coupling agents for polyethylene-based wood composites were investigated. Acrylates and methacrylates improve the resin-wood adhesive bond. It is thought that acrylates and methacrylates can be used to take advantage of unsaturated bonds in polyethylene as crosslinking sites. Composites consisting of 60% maple (*Acer saccharum*) wood flour, 35-40% low-density polyethylene (LDPE), and 0-5% radiation-curable metal acrylate and methacrylates were extruded and subjected to 80 kGy of high-energy electron beam radiation. Although the bending moduli of the samples were not significantly affected, the combination of the acrylate additives and radiation treatment improved strength and toughness over controls. In addition, the composites demonstrated improved moisture performance with exposure to electron-beam radiation.

Morphology of Wood Species Affecting Wood-Plastic Interaction: Mechanical Interlocking and Mechanical Properties

William Gacitua E., Ph.D. Candidate, Civil & Environmental Engineering and Research Assistant, and **Michael P. Wolcott**, Professor, Composite Materials Engineering/Adhesion and Research Director, Wood Materials & Engineering Laboratory, Washington State University, Pullman, Washington, USA

The surface topography of the solid phase is important in providing physical interactions between wood and thermoplastics; however, this aspect has not been completely addressed in the scientific literature. The main objective of this research is to address information to quantify anatomical features that could relate to the interaction between a molten thermoplastic with the wood cell structure and finally the resulted mechanical properties of the composite. Using a vacuum bagging process and scanning electron microscopy (SEM), the mechanical interlocking between wood species from small-diameter logs and high-density polyethylene (HDPE), without coupling agent and additives, had been studied. The vacuum and pressure at high temperatures help for melting and flowing of the HDPE mainly through the radial face (tangential direction) in small softwood samples, generating a 3D interpenetration of the thermoplastic into the cell wall structure. As a result, a contact interfacial area HDPE-cell wall appears. According to the SEM analysis, the presence of simple pits, their size and distribution on the cell wall create a potential path for the transverse movement of HDPE. Also, the collapse of cell walls under pressure during the vacuum bagging experiment was identified as a competing phenomenon avoiding the free flow of the molten thermoplastic. Penetration and interface area are significantly affected by the presence of earlywood or latewood. The wood specie Grand fir (*Abies grandis*) presented the highest interfacial area, which represent a potential for stress transfer in a composite. In a second experiment, composites were made using different wood species and the phase morphology was analyzed using SEM and image processing analysis. Wood species that in the previous experiment presented a high interface area have the potential for a better mechanical interlocking reflected on the viscous constant of the Maxwell model; model used to describe the interlocking mechanisms of the composite. It was observed that anatomical features of wood species play an important role in a real extrusion trial. The relation cell wall thickness/lumen diameter for each wood specie plus the interconnectivity between wood cells in a wood flour particle, through flow paths generated by pits, domain the collapse and potential penetration of the thermoplastic into the natural filler, which was analyzed as short fiber. Collapse of wood cells during extrusion reduced the potential surface for stress transfer between phases, affecting mechanical parameters of composites. On the other hand, undamaged wood cells are potentially filled with thermoplastic enhancing toughness and strength of the wood-plastic composites.

Reinforcement of WPC Materials with Bamboo and Abaca Fibers

A.K. Bledzki, Professor and Head, and **Markus Murr**, Scientific Staff – Dipl.-Ing., Institut für Werkstofftechnik Kunststoff- und Recyclingtechnik, Universität Kassel, Kassel, Germany

Wood and biofiber plastic composites have developed into a material that has established itself in the market place for some time. This paper describes possibilities for the improvement of impact resistance of wood-filled polypropylenes through addition of man-made and natural fibers. A much discussed topic with WPCs is the need to improve their impact resistance; also water absorption and the resulting swelling are of concern. The controlled application of additives only leads to a decrease of water absorption and of some mechanical values, but hardly influences the impact resistance. Through the addition of organic fibers, an increase in impact resistance is realized. The described tests include the application of Abaca- and bamboo fibers as well as the synthetic fibers such as PET and PAN. Shown are the influences of additives and the application of supplementary reinforcement fibers. The resulting value improvements are demonstrated. The cost comparison shows the economical advantages of natural fibers as compared to the mechanically superior synthetic fibers.

SESSION IIB: Mechanical Performance

Dynamic Mechanical Properties of Extruded Nylon-Wood Composites

Jianmin Chen, Post-Doctoral Research Associate, and **Douglas J. Gardner**, Professor of Wood Science & Technology, Advanced Engineered Wood Composites Center, University of Maine, Orono, Maine, USA

The Advanced Engineered Wood Composites (AEWC) Center at the University of Maine has developed a patent pending process to extrude nylon-wood composites. The combined factors of nylon-wood formulation and extrusion process parameters stabilize the wood and lower the melting point of the nylon. The nylon-wood composites have better material properties in strength, rigidity, temperature, and stability compared to pure nylon 6, 6. Dynamic mechanical properties help determine the end-use of the newly developed extruded nylon-wood composite. In this paper, the dynamic mechanical property characterization of extruded nylon-wood composites were conducted by means of a Dynamic Mechanical Thermal Analyzer (DMTA), which includes storage modulus characterization, glass transition (T_g) measurement, physical aging effects, long-term performance prediction and comparisons to similar products. The storage modulus of nylon-wood composite was found to be more temperature stable than pure nylon 6, 6. The T_g range of the nylon-wood composite was found to be between 23°C to 56°C, based on the decrease in storage modulus. A master curve was constructed based on the creep curves at various temperatures, 30°C to 80°C. The results show that the relationship between shift factors and temperature follows Arrhenius behavior. Nylon-wood composites have good temperature dependent properties. Wood fillers reduce the physical aging effects of nylon in the wood composites. The comparison of the nylon-wood composite with other similar nylon composite products indicates that the nylon-wood composite is a promising low-cost material for industrial applications.

Characterizing WPCs via Data-Driven Methodologies

John G. Michopoulos, Research Scientist/Engineer and Director, Computational Multiphysics Systems Laboratory, Center of Computational Material Science, U.S. Naval Research Laboratory, Washington, D.C., USA; **John C. Hermanson**, Research Engineer, USDA Forest Products Laboratory, Madison, Wisconsin, USA; and **Robert Badaliane**, Affiliate Professor, Department of Mechanical & Industrial Engineering, Montana State University, Bozeman, Montana, USA

The recent increase of wood-plastic composite (WPC) materials in various structural application areas has underlined the need for an efficient and robust methodology to characterize their nonlinear anisotropic constitutive behavior. In addition, the multiplicity of various loading conditions in structures utilizing these materials further increase the need for a characterization methodology that accounts for this complexity. In responding to these needs, this paper presents a data-driven methodology that utilizes multi-degree of freedom mechatronic loading systems to systematically collect behavioral data of specimens constructed from these materials. These data represent the force, stiffness, and Dissipated Energy versus displacement data for each specimen tested. The highly nonlinear behavior of these specimens was

confirmed and discussed in the context of the associated damage strain-induced microcracking. The difference of matrix material was found to exhibit a significant behavioral difference when compared among four different choices. This methodology, further utilizes the acquired data to construct an analytically defined model of the observed behavior in terms of identifying the total (recoverable and irrecoverable) energy density spent for deforming and damaging these materials. A constrained optimization formulation leads to the determination of the unknown parameters defining this formulation. Comparisons of the dissipated energy density distributions for the four selected materials underline the significant differences of the bulk materials involved. Subsequently, the identified constitutive behavior in terms of the dissipated energy density is utilized to predict load-displacement behavior of specimens tested outside the context of the automated loading frames utilized for the characterization. Validation discussion between the predicted behavior and the experimentally established behavior conclude this work.

Physical and Mechanical Properties of Novel Layered Composites of Wood Flour and PVC

Mehdi Tajvidi, Assistant Professor, and **Shayesteh Haghdan**, Student, Department of Wood & Paper Science & Technology, Faculty of Natural Resources, University of Tehran, Karaj, Iran

Wood-plastic composites can be manufactured using methods other than conventional extrusion or injection molding systems. A promising method, which is economically advisable, is using a hot-press to produce wood-plastic panels. However, such composites will suffer from inferior flexural and other mechanical properties as compared with their extruded counterparts, mainly due to the discontinuity of the plastic phase at higher plastic contents. In this research, the possibility of employing thin wood layers to cover the faces of the produced panels during the hot-press process has been studied. Composites of wood flour, poly vinyl chloride (PVC), and maleated polyethylene (MAPE) were prepared in a hot-press at various PVC contents. Similar composite panels with thin wood layers on both faces were also prepared and their physical and mechanical properties were compared. Results indicated that flexural strength, flexural modulus, hardness, and nail/screw withdrawal resistances were all improved when the panels were layered. Flexural properties more than tripled in the case of layered composites. At the same time, the increases in water absorption and thickness swelling due to the presence of wood layers were negligible. The results confirm that using thin wood layers on the faces of such composites can considerably improve their mechanical properties while maintaining acceptable water absorption and thickness swelling.

Statistical Elastic and Creep Properties of Kenaf Fibers

Yibin (Anna) Xue, Assistant Research Professor, Center for Advanced Vehicle Systems, **Steve Elder**, Associate Professor, Department of Agricultural & Biological Engineering, and **Devin Shame**, Undergraduate Student, and **Mark Horstemeyer**, Professor and CAVS Chair, Mechanical Engineering, Center for Advanced Vehicle Systems, Mississippi State University, Starkville, Mississippi, USA. Presented by **Yicheng Du**, Graduate Research Assistant, Department of Forest Products, Mississippi State University, Starkville, Mississippi, USA

Plant bast fibers such as kenaf, hemp, and flax, have low density and high specific strength and are of utmost interest in applications striving for lightweight and high strength. Bast fiber-reinforced polymer-based composites have been successfully developed as interior panels for automobiles. The quality of fibers, the formats of fibers, and the interfacial bonding strength with polymer matrices are extremely important for advanced applications that require high strength such as sub-structural exterior components of automobiles. This paper presents multiscale experiments to evaluate the elastic and creep properties of kenaf fiber using nanoindentation and conventional uniaxial tension set-up on single fibers, fiber bundles, and fibers in sliver and yarn forms enhanced by epoxy resin, respectively. Kenaf fiber bundles are taken from three locations along the plant: near the root, in the middle, and near the top. The fiber bundle, in general, demonstrates brittle tensile fracture. Stepwise-reduction of the "nominal" modulus was observed sometimes when interfacial-fiber fractured before the complete failure of the fiber bundle. The cross-section area of the fiber bundles varies along the length and both elastic modulus and fracture strength have shown large scatter. Therefore, statistical mechanical properties are presented. Both tensile and creep tests are performed on the unidirectional kenaf fiber bundles in sliver and yarn forms. Creep tests at various constant stresses and elevated temperatures are conducted and a simple creep model is proposed. An analytical model is applied to estimate the modulus of the kenaf fiber using an inverse

approach. Optical and scanning electron micrographs are taken to observe the fracture surfaces and determine the failure mechanics. In addition, nano-indentation tests will be conducted on single kenaf bast fiber.

Fracture Behavior of WPCs

Li Dagang, Professor and Director, Department of Packaging Engineering, Nanjing Forestry University, Nanjing, P.R. China; **Wu Feng**, President, **Wu Zhengyuan**, Vice President, and **Ding Jiansheng**, General Engineer, Nanjing JUFENG New Materials Co., Ltd., Nanjing, P.R. China; and **Xu Xiaojun**, Lecturer, Department of Packaging Engineering, Nanjing Forestry University, Nanjing, P.R. China

We investigated the mechanical and physical properties as well as the fracture mechanisms of wood-plastic composites (WPC) made from rice hulls and recycled PE. We performed tensile, compression, three-point bending, nail-holding, and impact tests and also measured water absorption. Mode I fracture toughness was determined by testing pre-cracked tensile and bending specimens. Fracture mechanisms were ascertained by examining fracture surfaces. Material behavior followed Hook's Law at low strains and the elastic moduli were found to be similar in tensile and compression tests. The composites exhibited brittle behavior and the bending strength could be predicted using standard formulas. Both bending strength and fracture toughness decreased at low temperature, but were still higher than the unfilled plastic. The fracture surfaces showed brittle failure initiating from the interface between the rice hulls and plastic.

Effects of Water Absorption on the Mechanical Properties of HDPE/Wood Composites

Alireza Kaboorani, Ph.D. Student, and **Alain Cloutier**, Professor and Director, Department of Wood & Forest Sciences, Université Laval, Québec City, Québec, Canada; and **Michael P. Wolcott**, Professor, Composite Materials Engineering/Adhesion and Research Director, Wood Materials & Engineering Laboratory, Washington State University, Pullman, Washington, USA

Wood-plastic composites (WPC) have experienced considerable growth in the past two decades. The largest market for WPCs is decking board in which composites are exposed directly to water. As a hygroscopic material, wood exchanges moisture with its surrounding area. The hygroscopicity of wood results in water absorption of WPCs to some extent. Exposure to moisture can affect the structure and properties of the wood fibers, the plastic matrix, and the interface between both materials. Most importantly, shear stress developed by the swelling of the fibers leads ultimately to the delamination of the wood-plastic interface. This can result in a significant reduction in mechanical properties of WPCs. As the wood-plastic industry seeks new markets in the structural sectors and outdoor applications in which there is a high possibility of water exposure, developing a better understanding of the material response towards water exposure is becoming more important. In this study, changes in mechanical properties resulting from water exposure will be discussed. The mechanical properties were measured before and after water exposure. In order to understand the impact of the duration of the exposure to wet conditions on the properties, they were determined after three exposure times (4 weeks, 10 weeks, and 4 months exposure). The effects of formulation design on the mechanical properties loss were addressed as well.

TUESDAY AFTERNOON, MAY 22

CONCURRENT SESSIONS

SESSION IIIA: Matrix and Biofiber Interaction

Chemical Functionalization of Lignocellulosic Polymers for the Control of Interfacial Adhesion in Wood and Biofiber-Plastic Composites

Gilles Sèbe, Assistant Professor, Wood & Biopolymers Sciences Unit, Université Bordeaux 1, Talence, France

The mechanical properties of wood or biofiber plastic composites are strongly influenced by the quality of the fiber/matrix interface. The lack of compatibility between the hydrophilic lignocellulosic fibers and the hydrophobic matrix generally limits the strength performances of the composites, preventing their utilization in many structural applications. The interfacial adhesion can, however, be improved by physical and/or chemical means. Among the possible methods, the chemical

modification of lignocellulosic polymers offers the possibility to graft appropriate functions at the wood (or biofiber) surface, which can modify the fibers wettability (grafting of hydrophobic moieties for instance) or interact with the polymeric matrix (chemical coupling or physical entanglement). In this context, novel reaction pathways for the chemical functionalization of wood have been investigated and characterized at the molecular level. These modifications will be presented, with particular emphasis placed on methods involving organosilicon compound and transesterification reactions.

The Role of the Interphase in the Mechanical Stability of Adhesive Bonds in Wood

Wolfgang Gindl, Associate Professor, **Johannes Konnerth**, Ph.D. Student, **Thomas Schoeberl**, Senior Scientist, **Juergen Follrich** and **Andreas Valla**, Ph.D. Students, and **Ulrich Mueller**, Assistant Professor, Department of Materials Science & Process Engineering, BOKU-University of Natural Resources & Applied Life Sciences, Vienna, Austria

The growing importance of bio-based composites requires an improved understanding of adhesive bonding, which is one of the crucial processing steps in the production of such composites. By means of nanoindentation and electronic speckle pattern interferometry, we have performed extensive studies on the role of adhesive penetration into the wood structure on the micro- and nanoscopic levels. It was found that a certain amount of penetration of adhesive into the wood structure is probably beneficial to bond strength. According to our results, we propose that ideal adhesives should have an elastic modulus in the order the transverse elastic modulus of wood, and should be able to penetrate not only into wood cavities, but also into the wood cell wall. In the present paper, past results are reviewed and perspectives for future research, in particular, using new nanoindenter geometries, are discussed.

Probing the Transcrystalline Layer of a WPC with Nanoindentation

Joseph E. Jakes, Graduate Student and Researcher in Training, and **John C. Hermanson**, Research Engineer, USDA Forest Products Laboratory, Madison, Wisconsin, USA

Nanoindentation is capable of probing the mechanical properties of the transcrystalline layer (TCL) in a wood-plastic composite (WPC). After a polymer melt exits the extruder, the polymer cools and forms crystalline regions. For a WPC, the surfaces of the pieces of wood provide favorable nucleation sites for embryonic crystals and they grow and combine with neighboring embryonic crystals. They continue to grow until they reach the solid structure of the bulk polymer. This region between the wood and bulk polymer is the TCL. When a force is exerted on a WPC, it is hypothesized that the stress is transferred between the bulk polymer and wood through the TCL. Understanding the mechanical properties of the TCL is important in understanding the mechanical properties of the WPC. In nanoindentation, a diamond tip is pressed into a material while the force and displacement are recorded. From the force versus displacement curves, valuable mechanical information can be calculated. Using an atomic force microscope, individual images of the indents are created and from these images the areas are measured and the indents characterized. Using the measured areas and maximum load values, Meyer hardness values can be calculated. From the load versus displacement curves, an indentation modulus value is calculated utilizing the unloading slope and creep compliance is calculated from the constant load hold segment. This work demonstrates the ability of nanoindentation to probe the TCL of a WPC.

Evaluation of WPC Fiber Swell Behaviors Observed by Fluorescent Microscopy

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

Natural fiber composites prepared from wood fiber have been analyzed by fluorescence microscopy to observe the interfacial behaviors between the plastic and fiber and to characterize the extent of fiber swell in the composite. Wood-plastic composites (WPC) generated by injection molding were assessed in cross-section by microscopy during periodic wet and dry cycling to determine the extent of any fiber swell, deformation, and resulting interfacial behavior with the plastic matrix. Methodology has been developed using image analysis to calculate the relative swell of both matrix and fiber components as well as any dimensional change to the WPC profile. In assessing the effect of wet-dry cycling over a 100-day period, it was found the fiber tended to dominate swell characteristics of the composite matrix and that

the fiber-matrix interface is irreversibly distorted with some crack propagation.

Natural Fiber and Polyhydroxyalkanoate Composites: Performance Enhancement

Scott Anderson and **Jun Qian**, M.S. Candidates, **Jinwen Zhang**, Assistant Professor, and **Michael P. Wolcott**, Professor, Composite Materials Engineering/Adhesion and Research Director, Wood Materials & Engineering Laboratory, Washington State University, Pullman, Washington, USA

Poly(hydroxyalkanoates) (PHAs) such as the well-known poly(3-hydroxybutyrate) (PHB) and poly(3-hydroxybutyrate-co-3-hydroxyvalerates) (PHBVs), are directly produced from bacterial fermentation using sugars or enzyme thinned cornstarch as feedstock. PHB and some PHBVs demonstrate high tensile strength and modulus comparable to many fossil oil-based plastics (e.g. polypropylene). Niche applications of bioplastics such as utensils, food packaging, grocery bags, and mulch films, are emerging. However, PHAs and other bioplastics have only an insignificant share in the current marketplace dominated by fossil oil-based plastics. As the technology advances continue to reduce the production cost of the resin, developing cost-effective and performance enhanced products are critical to the promotion of PHA products in the conventional plastics marketplace. In this study, we investigated the preparation and properties of natural fiber-reinforced PHB and PHBV (containing 8 and 12 mol% of 3-hydroxyvalerate) composites. Natural fibers include wood flour and bamboo fiber. Titanate and zirconate (Lica), polymeric diphenylmethane diisocyanate (pMDI) and maleic anhydride grafted PHBV8 (MA-PHBV8, containing 0.3 wt% MA) were used and effects on properties was studied. Adding nucleating agent was also evaluated for the property improvement. The results suggest that both extrusion and injection molding resulted in products with comparable mechanical properties, with injection molding yielding slightly higher flexural strength and modulus. Titanate and Zirconate coupling agents did not improve the compatibility of PHBV and WF. In fact, increasing the addition of these coupling agents resulted in continuous decrease in mechanical properties. MA-PHBV8 improved the compatibility between the PHBV and WF. WF with finer particle size also increased the strength of the composites, but tended to decrease the modulus. SEM indicated that the addition of MA-PHBV8 resulted in better wetting of the fiber surface as less fiber pullout was shown, comparing to the untreated fiber. Similarly, untreated fiber appeared to be better wetted than fiber treated with the titanate or zirconate coupling agents. Bamboo fiber induced crystallization and poor formed transcrystallization layer (TCL) was observed. Adding boron nitride as a nucleation agent appeared to suppress fiber induced crystallization and interrupted the TCL formation, because spherulites initiated by nucleating agents outgrew that of fiber induced spherulites. Addition of the nucleating agent also resulted in increased tensile and flexural properties. Compared with the neat PHBV8, the glass transition temperature (T_g) of PHBV8 in the composites was increased slightly. When pMDI and MA-PHBV8 were used, both significantly increased the mechanical properties of the composites. On the other hand, both pMDI and MA-PHBV8 showed decreasing effects on T_g and crystallinity of PHBV8. Scanning electron microscopy revealed the increased wettability of BPF by PHBV8 and better dispersion of the fiber in the matrix with the addition of pMDI or MA-PHBV8.

Nanocomposite-Based Wood Fibers for Reinforcement in Thermoplastic Composites

Zhiyuan Lin, Graduate Student, and **Daniel P. Hindman**, Assistant Professor, Department of Wood Science & Forest Products, and **Richey M. Davis**, Associate Professor, Department of Chemical Engineering, Virginia Tech, Blacksburg, Virginia, USA; **Yuri Lvov**, Professor, Institute for Micromanufacturing, Louisiana Tech University, Ruston, Louisiana, USA; and **Scott Rennekar**, Assistant Professor, Department of Wood Science & Forest Products, Virginia Tech, Blacksburg, Virginia, USA

The interface between the reinforcing wood fiber/flour surfaces and thermoplastic matrix is vital to the performance of wood-plastic composites. We have developed a new paradigm for the design of the interfacial area by creating "nanocomposite-based wood fibers" that incorporate layer-by-layer (LbL) nanoscale coatings, where electrostatic attraction is used to assemble sequential layers of polyelectrolytes and nanoparticles, to tailor the performance of the wood-plastic composite materials. Related to the forest products sector, LbL assembled coatings have demonstrated utility in the area of pulp fiber modification for paper improvement. We have incorporated clay nanoplatelets

into the LbL structure to impact the durability of the fiber as well as included an ionic surfactant at the terminal coating layer to influence adhesion with the thermoplastic matrix. Because the LbL nanocoatings are applied to the fibers in an aqueous system, we have chosen a wet-lay process for composite processing. Overall, the composites can be fabricated with relatively low energy requirements – steam-explosion generates fibers without the use of disc refiners, surface modification occurs by ionic self-assembly in ambient conditions, and the nanocomposite-based wood fibers and matrix are combined within a wetlay process for composite production.

SESSION IIIB: Moisture and Durability

WPC Durability and the Compelling Case for Field Testing

Mark J. Manning, Global Manager, Preservation Technology, and **Fred M. Ascherl**, Technical Support Manager, Rio Tinto Minerals, Centennial, Colorado, USA

Wood-plastic composites (WPC) have become an integral part of the residential deck market in North America – their market share has more than doubled in the last 5 years and some estimates suggest they will surpass 30% of the market before the end of the decade. Initially, these materials were assumed to be inherently resistant to fungi and insects and were touted by the manufacturers as being a ‘maintenance free’ product. It was thought that the thermoplastic resin would completely envelop the wood particle, thereby protecting it against wood destroying organisms. The issue of WPC durability continues to receive considerable attention and is the focus of dedicated sessions at International Conferences such as this one in Madison. To date, standards and test methods that are utilized as part of the product development cycle have continued to focus on testing ‘virgin’, unweathered material and have, for the most part, overlooked the importance of rigorous, long-term field testing. By comparison, the development of wood preservatives to treat solid lumber for the residential deck market involves extensive field testing as a necessary component in the standards approval process. This paper will look at the issue of field testing as related to WPCs and highlight how such tests can yield a dramatically different perception of durability as compared to standard industry tests on unweathered material. These results from the field show that WPCs can achieve the necessary moisture content capable of initiating and supporting fungal decay.

Effect of Processing Variables on Water Absorption by PP-Based WPCs

Shu-Kai Yeh, Ph.D. Student, and **Rakesh K. Gupta**, Professor, Department of Chemical Engineering, West Virginia University, Morgantown, West Virginia, USA

Although wood-plastic composites (WPC) are widely used as decking materials today, they are susceptible to dimensional changes due to water absorption, and repeated cycles of moisture absorption and desorption can result in the loss of mechanical integrity. A partial solution to the problem is the addition of a coupling agent that not only increases WPC strength, but also decreases the rate of water absorption. In this study, we demonstrate that the effectiveness of the coupling agent can be increased by varying extrusion process conditions. Polypropylene (PP)-based wood-plastic composites were compounded using a twin-screw extruder, and the extruded strands were pelletized, dried, and injection molded into test specimens. The variables that were changed included extruder screw speed, screw geometry, and feed rate, all of which influenced the residence time in the extruder. The rate of water absorption by the injection-molded WPC samples having dimensions of 12.5 mm x 64 mm x 3.175 mm was determined using a “blot and weigh” method, and results were represented as percentage weight gained versus time of immersion. By changing extrusion conditions, it was found that while the mechanical properties of the WPCs depended on wood content, the rate of water absorption was a function of the specific energy input into the WPCs during compounding. In particular, high screw rotation speeds and low feeding rates gave lower rates of moisture absorption. Changes in screw geometry also led to changes in the rate of water absorption.

The Effect of Pretreatment on the Environmental Durability of Hemp Fiber-Reinforced Recycled Low-Density Polyethylene Composites

Stanley I. Aghedo, Graduate Student and Research Assistant, and **Caroline Baillie**, Professor, Department of Chemical Engineering, Queen’s University, Kingston, Ontario, Canada

Post-consumer plastic waste materials such as low-density polyethylene materials are being recycled and converted into useful products with an interesting combination of properties. The environmental performance of natural fiber composites is one such important property which is receiving much attention. The environmental durability and the effects of water sorption on the mechanical properties of short hemp fiber-reinforced recycled low-density polyethylene composites have been studied with special reference to fiber surface pretreatment. The goal of the study is to evaluate the potential of inexpensive methods of fiber modifications in improving the properties of fiber composites. Hemp fibers were pretreated by a hydrothermal method and by sodium hydroxide method, in our laboratory were used to fabricate composites. The effect of this pretreatment method on the environmental behavior of the fiber composites was investigated by monitoring the water absorption and the mechanical properties of the composites immersed in water from 1-8 weeks. The results of the sorption properties of untreated and pretreated fiber composites are presented together with the tensile and flexural properties of the degraded composites. An evaluation of the results to show the effects of such simple technique as hydrothermal and sodium hydroxide pretreatment methods on composites materials durability properties will be presented.

Chemical Modification of Wood Particles for the Production of WPCs Using N-Methylol Compounds and Paraffin

Anke Schirp, Project Leader, Fraunhofer Institute for Wood Research (Wilhelm-Klauditz-Institute), Braunschweig, Germany; **Bettina Stoll**, Graduate Student, and **Carsten Mai**, Research Scientist, Institute of Wood Biology & Wood Technology, University of Göttingen, Göttingen, Germany; **Eric Richter**, Technical Marketing Manager, Clariant GmbH, Gersthofen, Germany; and **Holger Militz**, Professor, Institute of Wood Biology & Wood Technology, University of Göttingen, Göttingen, Germany

Wood-plastic composites (WPC) exhibit several advantages compared to unfilled thermoplastics such as improved stiffness, thermal stability, and biodegradability, as well as lower cost. However, dimensional expansion of WPC due to water uptake of the hydrophilic wood filler has been identified as a major disadvantage of this material. The objective of this study was to improve WPC hydrophobicity by impregnation of the wood filler with three chemical modification reagents used as wrinkle-resistant finishes in the textile industry such as 1,3-dimethylol-4,5-dihydroxyethyleneurea (DMDHEU). The two N-methylol groups in DMDHEU are able to react with hydroxyl groups of the cell wall polymers; in addition, polycondensation of DMDHEU-molecules may occur. Three formulations based on polypropylene as the thermoplastic matrix material were used to manufacture injection-molded WPC. Mechanical and physical properties as well as durability of WPC against wood-decay and soft rot fungi were determined. The effectiveness of the wood modification treatments was analyzed using weight percent gain (WPG), Fourier transform infrared spectroscopy (FTIR) and carbon/nitrogen (C/N) determination. The results show that water uptake and dimensional expansion of WPC based on chemically modified wood particles were significantly reduced while no improvement of the mechanical properties and fungal durability was observed. The improvement in WPC hydrophobicity may be due to the fact that the reagents blocked the hydroxyl groups not only on the surface, as is the case with maleic-anhydride-modified polypropylene or polyethylene (MAPP or MAPE) treatment, but also in the bulk of the wood particles. However, the chemical modification reagents used do not act as coupling agents in WPC. The results will be presented at the conference in detail.

Moisture Sorption, Micromorphology, and Durability of WPCs made from Modified Wood

B. Kristoffer Segerholm, Ph.D. Student, and **M.E.P. Wälinder**, Assistant Professor, Department of Civil & Architectural Engineering, Building Materials, KTH, Royal Institute of Technology, and Research Scientist, SP Technical Research Institute of Sweden, Stockholm, Sweden; and **P. Larsson Breid** and **M. Westin**, Research Scientists, SP Technical Research Institute of Sweden, Borås, Sweden

Today, wood-plastic composites (WPC) are mainly used in outdoor applications (e.g. as replacement for traditional preservative-treated wood). In such environments, moisture sorption combined with temperature induced movements of the polymer matrix may cause macroscopic dimensional changes and distortion (e.g. warping, cupping, and bowing of the composite boards as well as microscopic wood polymer interfacial cracks). Moisture uptake (diffusion/capillary penetration) in the composite also makes the wood component more susceptible for fungal growth and decay. Furthermore, the durability of the composite product may be further decreased by UV degradation effects. By using a modified wood component which is less hygroscopic, these problems could be minimized or entirely avoided. The objective of this work is to study the moisture sensitivity of WPCs made from modified wood and the effects of moisture sorption on the composites micromorphology, wood polymer interfacial behavior, and durability. The three modification methods used in this work are acetylation, furfurylation, and heat treatment. The technique used for studying the composite micromorphology was based on LV-SEM (low-vacuum scanning electron microscopy) combined with a specially designed specimen preparation technique by UV-laser ablation. Results show that wetting and drying of WPCs result in severe inner micro-cracks and interfacial debonding. These effects are, however, greatly reduced for WPCs made from the modified wood used in this study. In addition, the resistance to decay by fungi of such WPCs is significantly improved.

WPCs with Reduced Moisture: Effects of Chemical Modification on Durability in the Laboratory and Field

Rebecca E. Ibach, Research Chemist, **Rebecca L. Schumann**, Physical Science Technician, and **Craig M. Clemons**, Materials Research Engineer, USDA Forest Products Laboratory, Madison, Wisconsin, USA

Although laboratory evaluations of wood-plastic composites (WPC) are helpful in predicting long-term durability, field studies are needed to verify the overall long-term durability. Field exposure can encompass numerous degradations (i.e. fungal, UV light, moisture, wind, temperature, freeze/thaw, wet/dry cycling, termites, mold, etc.) that traditionally are studied separately in the laboratory. Moisture sorption of WPCs is slower than in unmodified solid wood, but it affects the strength, stiffness, and ultimately the decay of the material. The objectives of this study were to: 1) investigate several methods of reducing moisture sorption and, consequently, fungal degradation; 2) compare the effects of moisture and fungal decay in wood flour-filled and wood fiber-reinforced HDPE; and 3) perform laboratory and field evaluations of WPCs specimens. The methods used to reduce moisture were: 1) acetylation of the wood; and 2) use of a coupling agent. Acetylation of wood esterifies the hydroxyl groups, making the wood more hydrophobic, dimensionally stable, and biologically durable. Coupling agents are known to promote bonding between the plastic and unmodified wood fibers when added to WPCs. WPC specimens were installed above-ground and in-ground in Saucier, Mississippi and Madison, Wisconsin, USA. WPC specimens have been evaluated for the past 2 years. Many observations have been taken and a rating scale is being developed. To monitor swelling of the specimens, thickness measurements were recorded. Acetylation of the wood fiber decreased moisture content and fungal decay compared with coupling agent and unmodified WPCs. Results will be discussed as well as correlation between laboratory and field.

COMBINED SESSION: Durability and Coatings**Effect of Accelerated Aging on the Physical and Mechanical Properties of WPCs**

Sreekala G. Bajwa, Assistant Professor, Department of Biological & Agricultural Engineering, University of Arkansas, Fayetteville, Arkansas, USA; **Alexander S. Anthony**, Student, Department of Physics, California Institute of Technology, Pasadena, California, USA; and **Dilpreet S. Bajwa**, Manager, R&D, Greenland Composites, Fayetteville, Arkansas, USA

The long-term performance of wood-polymer composites (WPC) under severe weather conditions has not been thoroughly investigated. This study was performed to evaluate the changes in physical and mechanical properties of WPCs in comparison to CCA-treated southern yellow pine (SYP) when subjected to a modified 6-cycle accelerated aging process. The experiment included four products (SYP and three different commercially available WPCs) and six cycles of aging, resulting in 24 treatment combinations. Out of the three commercial products, one was compression molded and two were extruded. Each cycle of the modified 6-cycle accelerated aging included 24-hr water soak at room temperature (25°C), followed by 24-hr freeze at -8.5°C, 2-hr (+30 min warm up) steam at 121°C, 14-hr oven at 71°C, and 24-hr of conditioning at room temperature. After each cycle, the samples were tested for surface defects, specific gravity, water absorption, linear coefficient of thermal expansion (LCTE), flexural modulus of elasticity (MOE), flexural modulus of rupture (MOR), compressive strength, hardness, and screw withdrawal strength, following ASTM standards 7032 and 1037. The results of this experiment clearly demonstrate the differences in the physical and mechanical properties of both WPCs and CCA-treated SYP after 6-cycles of accelerated aging. CCA-treated SYP exhibited severe warping, splitting, and discoloration, whereas polymer-composites experienced slight discoloration, twisting, and charring. There was some decline in the MOE and rupture of WPCs after aging, while treated lumber remained unaffected. In WPCs, water absorption increased with every cycle contrary to treated pine. The coefficient of thermal expansion was positive for WPCs, whereas CCA-treated SYP exhibited negative values (shrinkage).

Surface Characterization of Weathered WPCs Produced from Modified Wood Flour

James S. Fabyi, Graduate Student, and **Armando G. McDonald**, Professor, Department of Forest Products, University of Idaho, Moscow, Idaho, USA; and **Nicole M. Stark**, Chemical Engineer, USDA Forest Products Laboratory, Madison, Wisconsin, USA

The effects of weathering on the surface properties of wood-plastic composites (WPC) were examined. Polypropylene (PP)-based WPC made from modified wood flour (untreated, extractive free, and holocellulose (delignified) fibers) were subjected to accelerated (xenon-arc) and outside weathering. Colorimetry, UV-VIS, FTIR, and x-ray photoelectron spectroscopies (XPS) were employed to monitor the color change, chromophores generation, and surface chemistries on the weathered WPC surface. The compositional changes that occurred on the WPC surface was determined using pyrolysis GC-MS analysis. The study showed that longer exposure time caused more chromophores generation, higher oxidation, lower wood lignin, and higher plastic content on weathered WPC surface. From this study, holocellulose-based WPC had less color change compared to untreated wood-based WPC. Details on the weathered WPC materials will be discussed.

Radiation Induced Degradation of WPC in the Field and in Laboratory Conditions

Marek Gnatowski, Technical Director, **Cecilia Stevens**, Senior Chemist, and **Mathew Leung**, Chemist, Polymer Engineering Co. Ltd., Burnaby, British Columbia, Canada

Degradation of wood-plastic composite (WPC) materials exposed to radiation generated by the sun is an important factor affecting durability. This degradation is mainly caused by UV and IR radiation from the sunlight spectrum creating damage to the material surface and subsurface regions. The presented work is dedicated mainly to photooxidation of the polymeric binders in WPCs and the method of quantitative evaluation of this degradation in controlled laboratory conditions (accelerated weathering) and comparison to data for materials exposed in the field for prolonged periods of time (some samples estimated at approximately 10 years old). An initial evaluation of the UV degraded region of the samples was done using optical and micro Raman spec-

troscopy with the focus on distance of degradation from the surface. The quantitative progress of laboratory and field weathering of the polyethylene of WPC containing a variety of additives such as a hindered amine light stabilizer system and zinc borate, was monitored with semi-micro FTIR spectroscopy. A special method was also developed to separate the polymeric binder from the wood in the degraded subsurface zone, which allowed for a quantitative long-term weathering assessment and a comparison rate and mechanism of accelerated weathering versus field exposure. Photooxidation of this polyethylene was evaluated using FTIR transmission spectroscopy. Polymer degradation was also assessed by DSC from the increase in heat of crystallization observed. Based on micro-FTIR and photomicrography, it was found that a region of strong UV degradation may progress as deep as 0.5 mm below the WPC surface. While ATR spectroscopy data showed fast plateau development over the exposure time, it was found that FTIR transmission spectroscopy had potential for quantitative evaluation of the rate of degradation of WPC after prolonged UV exposure in laboratory and exterior conditions. It was also confirmed by a detailed analysis of transmission FTIR spectra that accelerated weathering exposure such as fluorescent light apparatus (QUV), seemed to generate a similar photodegradation mechanism as sunlight in the polyethylene of WPC. Prolonged exterior exposure caused not only photooxidation, but also molecular weight degradation in polyethylenes visible as an increase in the DSC data. WPC exposed to exterior conditions for a prolonged period of time showed significant oxidation and degradation of the material interior along with photooxidation of the surface, which seemed to have a different oxidation mechanism. This interior oxidation was not directly related to the decay process observed in wood.

Coating of WPCs

Marie-Pierre G. Laborie, Assistant Professor, and **Barun S. Gupta**, Graduate Research Assistant, Wood Materials & Engineering Laboratory, Washington State University, Pullman, Washington, USA

Wood fiber-reinforced thermoplastic polymer composites (WPC) are gaining increasing importance in exterior applications including decking, fencing, railing, and paneling. These applications would greatly benefit from the ability to coat WPCs. Unfortunately, there is currently little knowledge on the surface properties of WPCs and on the ability to coat WPCs. In addition, the low surface energy of plastics suggests that WPCs may be difficult to adhere to and require surface activation methods prior to coating. In this perspective, the objective of this research was to evaluate the surface properties and coating adhesion of a series of WPC formulations. In addition, the efficacy of surface activation methods that are commonly used on neat polyolefins was evaluated on WPCs. To that end, the surface chemistry of WPCs was characterized by Fourier transform infrared spectroscopic analysis (ATR-FTIR). Dynamic contact angle analysis (DCA) was used to characterize wettability. Finally, the adhesion of an acrylic primer to WPCs was evaluated with an 180° peel test. WPCs were found to be heterogeneous, low surface energy substrates. The peel adhesion of the acrylic coating on WPCs was intermediate to that on wood and on the neat plastics. Surface activation methods were effective at enhancing the adhesion of the acrylic coating to WPCs. In particular, the plasma and chromic acid treatments raised the peel adhesion of the acrylic coating on WPCs to levels comparable to those obtained on neat wood. The adhesion enhancement mechanisms could be understood based on the chemical and physical changes imparted by the treatments on WPC surfaces.

Solid Color Deck Stains: Meeting the New Needs of the Decking Market

Shelly R. Fox, Scientist, Rohm & Haas, Charlotte, North Carolina, USA

The changing decking market offers new products to consumers and new challenges to coatings manufacturers. The voluntary phase out of CCA-treated wood for residential applications at the end of 2003, opened up the decking market to new wood treatments that are environmental friendly and composite decking materials, composed of wood flour or fiber and plastics. The composite decking market is continuing to grow, becoming more popular due to the advantages over wood decking materials. The findings from our studies on composite decking will be presented and identify polymers that have excellent adhesion and durability on these new substrates.

Designing a Selectable Performance Colored Capstock Offering Scheme with Regards to Weatherability and Cost

Christopher E. Richards, Mechanical Engineer, Aspen Research Corporation, White Bear Lake, Minnesota, USA

This presentation will discuss the considerations made when selecting a range of products for use in a "Good, Better, and Best" scheme of weather resistant and cost-effective capstock material offerings. Specifically, this paper will discuss the requirements of a weather resistant material in terms of color and gloss fastness and durability with direct trade-offs to cost.

POSTER PRESENTATION ABSTRACTS

POSTER 1

Modeling WPCs Using Nonlinear Uniaxial Data

Nathan J. Bechle, Research Assistant, Department of Civil & Environmental Engineering, University of Wisconsin, Madison, Wisconsin, USA; and **John C. Hermanson**, Research Engineer, USDA Forest Products Laboratory, Madison, Wisconsin, USA

Biofiber-plastic composites are known to exhibit nonlinear load-displacement behavior when loaded at small time scale standardized test rates (1% strain per minute). The observed nonlinear behavior in tension, compression, and shear is unique to each mode of loading. Flexural loading incorporates all three aforementioned loading modes, therefore, in accordance with conservation of energy, each unique behavior must combine to yield the observed flexural behavior. As part of a broader study to determine the large time scale behavior of wood-plastic composites (WPC), the small time scale mechanical properties of six diverse formulations of extruded WPCs were established using small coupons cut from full size structural components. To determine the nonlinear stress-strain relationships for the six different formulations, testing was conducted in tension (ASTM D638), compression (method developed by the authors), and flexure (ASTM D790 – to obtain the shear modulus as described in ASTM D198 Appendix IV). A function of strain with both linear and inverse-hyperbolic sine terms accurately represented the observed stress-strain behavior. The resulting equations were included in a user defined material model within a finite element analysis to verify the functional representation of the different loading modes with the conservation of energy. The load-displacement output from the finite element analysis of full-size members in flexure accurately depicted the load-displacement measured for the corresponding specimens. Having verified the stress-strain relationships for small time scale, they will be utilized as a basis for the large time scale model development.

POSTER 2

Particleboard Produced from Planer Shavings with Natural-Fiber Reinforcement

Evandro Bittencourt, Professor, Materials & Management Science, Research Coordination of Management Department, University of the Region of Joinville, Joinville, Brazil

This work presents the results of the processing and characterization of particleboard consisting of planer shavings from furniture manufacture. The planer shavings particles are improper for the particleboard processing due to the differing formats and its natural concavity. This feature of particles generates particleboard of low mechanical properties. Sometimes, only one certain amount of planer shavings particles are used in the manufacture of particleboard. In the first stage, the work involved the processing study varying the particle size. The second stage includes the natural fiber upgrade as reinforcement. The used fiber was of sisal (*Agave sisalana*), banana fiber, sorghum fiber cutter on length of 2 cm and wood fiber (softwood) in additions of 5, 10, and 15%. The addition of natural fiber was moving the mechanical and physical properties in a market manner. The modulus of rupture (MOR) had a relative upgrade of 33% with the addition of only 10% of sisal fiber of 2 cm, in a similar way there was a significant upgrade in the force of pulling-up screws as well as an improvement in the water absorption and the swelling. The other fibers had similar results. By this means, the particleboard produced from planer shavings becomes technical viable. Moreover, the residue user becomes the industry of the wood most sustainable.

POSTER 3

Chemical Tailoring of Cellulose-Nanofibrils and their Applications in (Bio)Composite Materials

Nico C. Bordeanu, Post-Doctoral Scientist and Project Leader, **Tanja A. Zimmermann Schütz**, Senior Scientist, and **Klaus Richter**, Head, Wood Laboratory, Swiss Federal Laboratories for Materials Testing & Research (EMPA), Dübendorf, Switzerland

Wood derived cellulose fibrils at the nanoscale are promising for reinforcement and controlled modification of polymer matrices. It is feasible that mechanical properties of polymers and their functionality can be designed by compounding properly processed and refined cellulose fibrils. In order to induce an optimal compounding of the fibrils with different (bio)polymers, good fibril/matrix embedding is required. Therefore, the cellulose fibrils must be modified approximately to match the hydrophilic or hydrophobic nature of the polymer matrix. This paper will provide insights into our research regarding the chemical tailoring of cellulose fibrils for applications in wood adhesive (e.g. one component polyurethane adhesives, 1c-PUR) as well as for the compounding with (bio)polymers (e.g. polylactic acid, polypropylene, low-density polyethylene) for (bio)fiber production. Suspensions of cellulose fibrils resulting from the homogenization of bleached wheat straw pulp were chemical surface treated using mainly esterification and etherification reactions (e.g. silylation, acetylation, allylhydroxypropylation, etc.). The resulting dry chemical modified cellulose fibrils were characterized by spectroscopical (NMR, FTIR, XPS) and morphological (SEM-EDX, TEM) methods. Dry silylated fibrils could be dispersed successfully in the polyol component used for the preparation of 1c-PUR. The properties (morphology, rheology, gluing, thermo mechanics) of silylated cellulose fibrils based 1c-PUR adhesives are discussed and compared with adhesives prepared with un-derivatized fibrils (derived from aqueous fibril suspension).

POSTER 4

A Novel Method to Isolate Micro/Nanofibril from Cellulose Fiber and its Reinforced PVA Nanocomposites

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Natural cellulose micro/nanofibrils (CMNFs) are relatively new reinforcing materials for polymer composites, which have potential lightweight and high strength and are biodegradable. A novel process was developed and used to isolate CMNFs from natural cellulose fibers in this study. A mixture of fibrils in micro and nano scales was generated. The geometrical characteristics of CMNFs were investigated using polarized optical microscopy, scanning electron microscopy (SEM), and atomic force microscopy (AFM). CMNFs' crystallinity was investigated by wide angle x-ray diffraction (WAXD). The degree of fibrillation of the fibers is indirectly evaluated by water retention value (WRV) using a centrifuge system. CMNF-reinforced PVA nanocomposites were prepared by film casting. Mechanical properties of the nanocomposites were evaluated by tensile test and its morphological characteristics were investigated with AFM. As reference, a commercial microfibrillated cellulose (MFC) was used to compare the reinforcement with CMNFs.

POSTER 5

Mechanical Properties of a Single Natural Cellulose Micro/Nanofibril

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Cellulose microfibril and/or nanofibrils are very attractive to researchers and manufactures as reinforcing materials for polymer composites in the past decade because they are environmental friendly, the most abundant natural biopolymer in the world, and most of all, they have potential lightweight and very high strength. They are generally prepared by a physical treatment or chemical treatments. It is difficult to measure their mechanical properties directly due to their tiny dimensions, but the mechanical properties are important and useful for material reinforcement. In this study, attempts have been made to measure and evaluate the mechanical properties of a single natural cellulose micro/nanofibril.

POSTER 6

Flow Properties and Durability Assessment in WPCs

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Wood flour is gaining increasing popularity as established fillers in thermoplastic composites. The wood flour intrinsic properties combined to resin formulation and the type of coupling agent employed determine the flow properties and the melt processing conditions of the composite for further applications and use. In this work, commercial types of the maleated coupling agents with varying molecular weight and MAH graft content were tested to improve the filler-matrix interface adhesion and durability of polypropylene wood composites. The Heat Distortion Temperature (HDT) has indicated considerable gain in stiffness of the polypropylene filled with wood flour. Thermally aged samples at controlled temperature and times presented gradual increase in stiffness. Further assessment of thermal stability using Oxidative Induction Time (OIT) for different formulations indicated changes in the oxidation mechanism when comparing neat polypropylenes' OITs to wood-plastic composites (WPC). UV stability was evaluated after weather-o-meter testing in terms of the sample yellowness using ΔE shift determined by the Color Test. Power law parameters determined by capillary rheometer, have shown no major deviations in flow properties for the wood composites compared to the neat resins. The results assure good moldability conditions for all formulations investigated although in some cases melt consistency may be quite sensitive to testing temperature.

POSTER 7

Properties of WPCs after Accelerate Aging Treatment

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Wood-plastic composites (WPC) are manufactured by low melting point thermoplastic and natural fiber materials such as wood flour and rice hull, etc., which have the advantages of plastic and natural fiber materials. However, they also have the disadvantages of absorbing water and decay easily. As many WPC products are applied at outdoor places at the present time, the research on the properties such as accelerate aging of WPCs is very important. The results: 1) At the same situation, the mechanical properties at different directions of the plank material is width direction high rather than thickness direction. 2) The environment's cycle effects can accelerate the destruction of the interface between rice hull and polyethylene, and also the rupture of the matrix's molecular chains. Thus, the α relaxation was reduced. A lot of micro-cracks on the surface of the material lead to bad properties. And we put forward the formula, $FGI = \text{Absorbency of the evaluated functional group} / \text{Absorbency of asymmetryflex vibration of Si-O}$, which can evaluate the Functional Group Index (FGI). 3) Under -30°C , the FTIR spectra absorbency peak inside materials increased and the FTIR absorbency peak outside materials decreased. Under circulation, the absorbency peak inside material increased and the absorbency peak outside materials increased. Under 60°C , the absorbency peak inside materials decreased, and the absorbency peak outside materials increased.

Study on the Durability of WPCs

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Considering the research has relationships with the original properties of WPC, we first studied the performance of the raw and processed materials. Second, we emphasized and researched the changed characteristics of wood-plastic composite (WPC) under outdoor weathering. The change of weight and micromechanics was analyzed. The changes

of WPC's properties were observed and analyzed by using four high-tech instruments: Fourier-transform infrared spectrophotometer, differential scanning calorimetric, dynamic mechanical analysis, and scanning electron microscope. The result showed that the endothermic peak at near 60°C was the result of the decalescence of the desorption of rice hull's cellulose's adsorptive water. The melting point of HDPE in new WPC was 126°C. Finally, we simulated various environmental factors (water, seawater, acid rain, fungus, ultraviolet radiation) at the lab conditions, and drew some conclusions: 1) In the artificial simulated water conditions, the dimension change's rule of different directions was width > thickness > length. In the same time conditions, the mean ratio value of different directions at various disposal conditions was width/length = 2.31, thickness/length = 1.87, width/thickness = 1.34. 2) In the artificial simulated conditions, the micromechanics' properties of the material showed the same decrease trend. The weight of the material's pieces gained in the artificial simulated seawater conditions. In the same time conditions, the gain range of wood was larger than WPC. The ratio was about 17. In the artificial simulated acid rain conditions, the more acid it was, and the more bad properties. The weight of WPC gained in the artificial simulated fungus conditions and the gain rate was 0.78%. In the artificial simulated ultraviolet radiation and water together conditions, the absorbency peak of methylene - CH₂ distortion vibration and C = O flex vibration increased higher than that at outdoor weathering. This phenomenon showed that the effect of ultraviolet radiation on the properties of WPC was very large.

POSTER 8

Water Absorption Performances in WPC Materials

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The tendency of wood-plastic composites (WPC) to absorb moisture is very important in the processing and also in mechanical properties, appearance, and dimensions. Swelling of natural fibers can lead to cracking of the material, degradation, and poor mechanical properties. The potential effect of water absorption on WPCs is discussed based on known results from a long experience in testing *Enviroshake*[®] engineered roofing material. This paper contains data obtained in the laboratory as well as in the field. The effect on composite properties of change in moisture content due to water absorption depends on the type of exposure (by immersion in water or by exposure to high humidity), shape of the part, and inherent properties of the material. With non-homogeneous materials such as *Enviroshake*[®], the rate of water absorption may be widely different through each edge and surface. An in-house method based on ASTM D570 was employed to study the effects of exposure to water or humid conditions for WPC material. To verify the acceptability of the roofing product characteristics and process capability, some daily QC test results have also been analyzed. Water absorption (24 hours) average was 1.12% while the maximum admissible is 3%; values were between 0.50 and 2.17%. All data (approximately 5500) have been summarized graphically. None of the samples showed any signs of cracking, spalling, or other forms of deterioration. However, the frequency and amplitude are not uniform, the curve having a random aspect, which makes difficult to do estimations or find an empirical formula.

POSTER 9

Application of Mediators in Enzymatical Activation of Binder-Free Cohesions for the Production of Enzyme-Bonded, Binder-Free Derived Timber Products

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This project is about the substitution of petrochemical components in binders for derived timber products (esp. MDF) by using a system of enzyme and mediators, which operate as redox molecules between enzymes and lignin. The enzymes are produced by lignin-decomposing fungus (e.g. *Trametes versicolor*) in fermenters and after addition of mediators the enzyme-mediator-solution will be mixed with wood fibers for pressing of medium density fiberboards (MDFs). The aim of the first step is to increase the surficial structure of the wood fibers (*Pinus sylvestris*) through enzymatical activation of the own cohesions. Results of the incubation of the wood fibers with enzyme-mediator-mixture show a significant increase of the radical-density of the wood fibers, which achieve higher mechanical and technological attributes of MDF instead of solely enzyme-bonded MDF. The second step is the industrial production (in cooperation with Pfleiderer AG, Arnsberg,

Germany) with testing of all relevant attributes facing international standards. First results of the production of boards (started in August 2006) will be presented. The sustainable aim of the project is the reduction of using petrochemical binders in the MDF production because of the rare and expensive fossil resources, which is a contribution to ecological and economical aspects of the derived timber product industry.

POSTER 10

Isolation of Cellulose Microfibrils from Musaceas Agricultural Residues

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Today, many studies about nanocomposites are being carried out around the world. In this topic, one of the important keys is related with cellulose microfibrils as nanoreinforcement. Agricultural wastes appear as a cheap and vast potential cellulose resource. One of these cases are wastes from *Musaceas* comestible fruit production. These crops are an important economical activity in developing countries like Colombia. After harvesting and fruit packing, more than 4 millions tons of agricultural residues per year are generated because of the fruit only represents 12 wt% of plant. Cellulose microfibrils can be isolated from cell wall of fibrous residues as bunch, stem, or leaf sheath. In this work, different chemical and mechanical processes have been evaluated. Chemical treatments include alkaline, alkaline peroxide, and acidic steps. For mechanical treatment, a homogenizer machine has been used. Chemical characterization using FTIR spectroscopy and thermal analysis using DSC and TGA have been carried out. For morphological analysis of isolated cellulose microfibrils, transmission electron (TEM), and atomic force (AFM) microscopies have been utilized. Chemical treatments are useful to isolate cellulose microfibrils from primary cell wall. However, higher microfibril water dispersion can be obtained by the combination of chemical and mechanical processes.

POSTER 11

Poly(ϵ -Caprolactone) Grafted on Cellulose Microfibrils

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In recent years, several works about biodegradable composites have been developed. These materials offer an appropriate combination of mechanical and thermal properties with biodegradable behavior. However, in some cases, a lack in the fiber-matrix interface is observed. Different alternatives to improve this interfacial interaction have been proposed. Some of them include fiber treatments or grafting polymerizations on reinforcement surface. In this work, a biodegradable polymer as poly(ϵ -caprolactone) (PCL) has been grafted onto the surface of cellulose microfibrils. The ring-opening polymerization (ROP) of ϵ -caprolactone (CL) has been used. The hydroxyl groups on cellulose act as initiator, the tin octoate (SnOct₂) as catalyst, and the benzylalcohol as co-catalyst. The grafted cellulose microfibrils were characterized with Fourier transform infrared spectroscopy (FTIR), thermogravimetric analysis (TGA), differential scanning calorimetry (DSC), and x-ray diffraction analysis. Mechanical properties of the PCL composites with ungrafted and grafted cellulose microfibrils have been evaluated using tensile test. According with these results, the mechanical properties of the PCL composites are better than that of the neat matrix.

POSTER 12

Characterizing the Mechanism of Improved Adhesion on Modified WPC Surfaces

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To have a better knowledge of the phenomena that affects the adhesive characteristics of wood-plastic composites (WPC), and improve their adhesion properties, mechanical, physical, and chemical surface treatments were performed. The mechanical treatment of the WPC surface included changing surface roughness by abrasion treatments. The physical treatments included absorption and swelling using water and a combination of flame-water and water-flame. The chemical treatments consisted of surface oxidation using chromic acid, hydrogen peroxide, a low temperature flame (80-100°C), and a high temperature flame (180-220°C). After each treatment, the samples were prepared for the determination of their adhesive shear resistance, according to ASTM, and the surfaces were also characterized using thermodynamic, microscopic (SEM), profilometry and spectroscopic techniques (attenuated total reflectance Fourier transform infrared spectroscopy (ATR-FTIR) and x-ray photoelectron spectroscopy (XPS)). According to the results, all the treatments studied improved the surface bondability of WPCs. The smoothest WPC's surfaces seem to have better bondability compared with those having more roughness. The increase corresponded to more than 100% with respect to the control. In case of physical treatment, the combination water-flame increases the shear resistance in 80% with respect to the control. For the chemical treatments, the low temperature flame and chromic acid treatments produced higher levels of oxidation on the surface and improved the bondability of the samples. Those treatments increased the shear resistance of the samples 95 and 70%, respectively with respect to the control. A combination of mechanical, physical, and chemical treatments on WPCs could be the next step in the present research.

POSTER 13

Manufacture of Extruded Wood-Nylon Composites: Processing and Properties

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The application of wood fillers in higher melting temperature polymers such as engineering thermoplastics, has been limited because of the problems associated with wood thermal decomposition during extrusion processing. The work presented here will discuss the manufacture of extruded wood-nylon composites based on patent pending processing and formulation technology developed at the University of Maine, Advanced Engineered Wood Composites Center. Various wood-nylon composites formulations based on pine and nylon 6, 66 were processed on a Davis Standard Woodtruder, and flexural and tensile properties were determined. It was possible to extrude wood-nylon composites containing up to 55% wood flour. Flexural strength of the wood-nylon formulations varied from 7,000 to 13,000 psi, flexural stiffness varied from 365,000 to 885,000 psi, and tensile strength varied from 2,300 to 8,000 psi. The results suggest that opportunities exist to expand the use of wood fillers in nylon composites.

POSTER 14

Chalking and Surface Deterioration of WPC by Weathering Trials

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The market for wood-plastic composites (WPC) is expanding rapidly in many countries including Japan, where WPC are mainly used for exterior products. In such applications, WPC undergo undesirable color change, chalking and dimensional changes, and accordingly there is a need to better understand the mechanisms responsible for the weathering of WPC and develop methods of improving their weathering resistance. In this study, weatherability of WPC (wood fiber and polypropylene composites) was assessed by natural and accelerated weathering trials. It was observed by microscopic study that discoloration (whitening) of WPC without pigments during exposure was caused by degradation of both wood and plastic. On the other hand, darker color pigments as additives significantly improved color stability of WPC. However, chalking on the surfaces still occurred. The chalking powder generated by weathering was identified as mixture of wood and polypropylene by FTIR analysis. The color stability and chalking of WPC were improved by application of commercial exterior coatings. Pre-weathering of WPC before finishing increased the absorption of coatings because of improvement of wettability and generation of small cracks, and had a positive effect on the color stability and preventing chalking of the composites by accelerated weathering test.

POSTER 15

Nanoindentation of Unembedded Wood Cell Walls

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In situ testing of cell wall material using nanoindentation is a valuable tool to reveal the effects of chemical modifications on the material properties of wood at the level of the cell walls. Current practice in this field first involves embedding the wood in an epoxy matrix, then analyzing the nanoindentation data by tacitly assuming that the surface is homogeneous and infinite in size compared to the size of the indent. The problems with these procedures are that first, the embedment process may alter the mechanical properties of the cell wall, and second, the meso-structure of the wood may influence the nanoindentation measurement. We developed a method to prepare specimens with no embedment. The primary features of the resulting surface are cell walls (~5 µm wide) and empty lumens (~20 µm across). This is not the ideal surface assumed by standard nanoindentation methods. Indents performed in the cell wall material will be affected by the close proximity of the edge and by the open cellular structure which comprises the wood. We propose a nanoindentation method which accounts for edge effects and the structural compliance resulting from this cellular structure. To prove the efficacy of our method to account for edge effects, we placed indents near the edge of a standard fused silica specimen. Then, to demonstrate the capability of the method to account for structural compliances, we placed indents over the unsupported region of a silicon bridge structure. The literature values of hardness and Young's modulus were obtained from indents placed at the edge of the fused silica and over the unsupported region of silicon. Finally, we applied the methods to our wood specimens and found that we can separate out the effects of edges and compliant cell structure from the intrinsic properties of the cell wall material.

POSTER 16

Processing and Mechanical Properties of Highly Filled Cellulose Fibers Polypropylene Composites

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The goal of this study was to manufacture highly filled cellulose fiber polypropylene composites and to investigate their properties. Two grades of cellulose pulp were compared, a bleached sulphite pulp and a bleached kraft pulp. The cellulose pulp was pelletized prior to extrusion in order to achieve consistent feeding into the extruder. Cellulose fiber-reinforced polypropylene composites containing up to 60 wt% fibers were compounded with and without maleic anhydride grafted polypropylene using a co-rotating twin-screw extruder. The investigations were focused on the fiber breakage that occurred during processing, the mechanical properties of the composite materials, and the quality of the adhesion between cellulose fibers and polymer matrix. Both pelletization and extrusion were found to cause severe fiber breakage. The composite properties were found to not be affected by the nature of the cellulose pulp. The increased fiber loading was found to increase the composites stiffness, but to reduce the composites strength and toughness. The addition of maleic anhydride grafted polypropylene was found to improve the adhesion between cellulose fibers and polypropylene matrix and to increase the mechanical properties of the composites.

POSTER 17

Effects of Process Variables in the Steam Explosion Process on the Mechanical Properties of Thermoplastic Composites

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The use of natural fibers as additives for plastics has been rapidly expanding. Steam-exploded natural fibers from various bioresources have great potential as reinforcement of thermoplastic composites. Steam-exploded (SE) wood fibers tend to display large variation in their properties with processing parameters such as temperature, pressure, retention time, and feedstock conditions. The development of a simulation model for the fiber manufacture using steam explosion (SE) technique and the manufacture of wood fiber-thermoplastic composites can save time and cost for optimal processing. It is our focus to achieve optimum condition for SE process for wood fiber-thermoplastic composites using the simulation model. From acid pretreatment to the manufacture of plastic composites, principal major processing parameters will be examined and manipulated to find desirable quality of final products.

POSTER 18

Highly Deteriorated Beetle-Killed Spruce from the Kenai Peninsula, Alaska, as Raw Material Source in WPCs

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Over the past 20 years, bark beetles have devastated an estimated 1.5 million acres of spruce trees on the Kenai peninsula alone, and in many stands, up to 95% of the trees have been killed. Public and private landowners are now faced with the task of selectively removing the most hazardous material from nearby transportation and utility corridors, residences, and public buildings and have no market for the byproducts. Manufacture of wood-plastic composites (WPC) is less sensitive to the initial condition of wood raw material making them a possible use for beetle-killed material. We investigate the opportunity of using beetle-killed spruce in WPC production. The objectives were to characterize properties of raw material critical for WPC production; these include thermal characterization, chemical composition, and particle size analysis. Highly deteriorated sample trees were selected based on visual characteristics (bark mostly gone, no fine limbs, weathered gray coloration). Three 8-ft logs were taken from each tree:

one at the butt, one from below the 4-in top, and the third equidistant between those two. Varying proportions of wood flour from the three positions were used in WPC formulation. A limited number of specimens will also undergo chemical analysis to assess primary wood component ratios. Moisture absorption and thickness swell tests will be carried out as they are considered to be good indicators of composite durability. Results show that properties of WPC manufactured from highly deteriorated material are comparable to WPC properties produced using pine wood flour serving as a control material.

POSTER 19

Plasticization of Wood Fiber by Benzoylation

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The effects of chemical modification of wood flour on the moldability of this material were examined. Pine wood flour was chemically modified with benzyl chloride under alkaline conditions at various mole ratios of benzyl chloride to wood hydroxyl groups (BC/OH ratio = 1, 2, 3, and 4) and different reaction times. The extent of benzoylation was assessed by weight gain and FTIR spectroscopy. FTIR spectroscopy revealed the reduction of wood hydroxyl groups bands (3400-3500 cm^{-1}) and an increase in signals associated with aromatic groups (3092, 1950-1810, 1597, 936, 695 cm^{-1}), which were consistent with etherification. The thermal properties of the benzoylated wood fiber were assessed by dynamic parallel plate rheometry on pressed discs. Viscous flow (complex viscosity) was observed in benzoylated wood fiber between 78 and 161 °C. Results have also shown that the benzoylated wood thermal properties can be controlled by the extent of benzoylation. Results of conventional heating versus microwave assisted modification will be compared. The mechanical and processing properties of these modified wood fibers will be further discussed.

POSTER 20

Nano- Al_2O_3 Whiskers as an Additive for Amino Resin-Based Wood Adhesives – Effect on the Performance of the Wood-Wood Joints

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In our work, we investigated the effect of nano- Al_2O_3 whiskers addition on the physiochemical and mechanical properties of UF and MUF cured adhesive systems as well as the mechanical properties of the wood-wood joints. Two-layer beech wood assembly was used as a model for joint tests. Mechanical studies were performed on die-casted bar-shaped samples. It was found that low addition of nanoparticles significantly affects hardness and compressive shear strength of the cured polymer. It was also shown that blending UF/MUF resins with “nano-modifiers” can be an effective tool for controlling both physiochemical and mechanical properties of the cured adhesive systems.

POSTER 21

Investigation of Processing-Structure Relationship of WPC Foams by Using Design of Experiments

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Foaming of wood-plastic composites (WPC) 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. With the aid of design of experiments (DOE) technique, this paper experimentally investigates the relationship between the materials/processing parameters and the structure of WPC foams blown with physical blowing agents, which help elucidate the foaming behaviors under different conditions. Thereby, the material and processing conditions can be optimized to achieve the fine-celled structure of WPC foam in a cost-effective way.

POSTER 22

Mechanical Properties of Cellulose Fiber-Reinforced High-Density Polyethylene Composites

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This paper investigates effects of fiber length on mechanical properties of cellulose fiber-reinforced high-density polyethylene composites. Three types of fibers with different length (60 μm , 200 μm , and 700 μm) are used in this study. All the fibers used have similar thickness (1-2 μm) and width (20 μm). In addition, effects of functionalized polymers on mechanical properties of the composites are investigated. Four types of functionalized polymers (coupling agents) are used to modify the interface between the cellulose fiber and high-density polyethylene. One coupling agent is a maleated thermoplastic polymer: maleated high-density polyethylene (HDPE-MA). The others are maleated elastomers: maleated styrene/ethylene/butylene/styrene copolymer (SEBS-MA), maleated ethylene/propylene/non-conjugated diene elastomer (EPDM-MA), and maleated metallocene polyethylene (mPE-MA). Cellulose fiber, polyethylene, and the functionalized polymers are melt-blended using a high-intensity kinetic mixer, and the blends are injection molded to produce specimens for characterization of mechanical properties. Mechanical properties of the composites are evaluated using tensile, flexural, and Izod impact tests.

POSTER 23

Studies of HDPE/Neem Bark Flour Bio-Composite

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This paper summarizes experimental studies on the mechanical properties of lignocellulosic filler-reinforced high-density polyethylene (HDPE) composites. Bark flour, the part of the tree that is not of much use, can be considered as novel filler for thermoplastic composites below 180°C. Bark powder from Neem (*Azadirachta indica*) tree of mesh size below 63 μm was used to modify the properties of HDPE. HDPE/bark flour composites with varied volume fraction (0-0.26) of filler were prepared by melt compounding on a twin-screw extruder. Mechanical properties such as tensile, flexural, and impact properties, were evaluated in the study. Flexural modulus and strength showed improvement with bark flour content, while tensile and impact decreased. Significant enhancements of the composite properties were achieved when maleic anhydride grafted HDPE (MAHDPE) was used as a coupling agent. Tensile modulus and strength increased when MAHDPE was used while MAHDPE had not much influence on elongation at break and impact strength. This was attributed to the formation of chemical and electrostatic bonds between HDPE/MAHDPE and bark flour resulting in improved mixing of the components. Differential scanning calorimetry (DSC) studies showed that the presence of filler as well as the coupling agent, retards the crystallization of HDPE in the composite, whereas scanning electron microscopy (SEM) showed improved dispersion and interaction of bark flour in HDPE matrix in the presence of the coupling agent, which in turn, affected the strength properties of the composites.

POSTER 24

Unidirectional Natural Fiber-Polyolefin Laminates: Thermal and Mechanical Properties

Sangyeob Lee, Post-Doctoral Research Scientist, and **Sheldon O. Shi**, Assistant Professor, Faculty of Wood-Based Composites & Engineered Wood Products, and **Yibin (Anna) Xue**, Assistant Research Professor, Center for Advanced Vehicular Systems, Mississippi State University, Starkville, Mississippi, USA

Kenaf bast fiber-reinforced polypropylene (PP) film laminates have been fabricated to evaluate thermal and mechanical properties. This experiment was also designed to evaluate fiber orientation, and furnish formulation effect on the properties of kenaf and polypropylene film laminates. The effects were evaluated by dynamic mechanical analyzer (DMA), differential scanning calorimetry (DSC), scanning electron microscopy (SEM), and tensile strength of laminates. The uniaxial fiber orientation provided better property performance on the storage

modulus (E') of laminates than randomly oriented kenaf fibers in the laminates. Thermal properties obtained from DSC showed that the melting point (T_M) was decreased and crystallization peak was increased with an increased weight fraction of kenaf fibers in the laminates. Morphology of the kenaf fiber surface and fractural surface of the laminates was examined and it showed that interfacial failure between fiber surface and matrix materials. Some of the fibers pulled out from the matrix. The tensile strength properties were increased with an increased weight fraction of kenaf fibers and number of fibers in the failure surface. The unidirectional fiber orientation provided about 60 to 95% better mean of property enhancement over the randomly oriented samples.

POSTER 25

High Strength PLA Composites with Cellulosic Fibers

Adam R. Jaszkwicz, Scientific Staff – Dipl.-Ing. and Ph.D. Student, and **A.K. Bledzki**, Professor and Head, Institut für Werkstofftechnik, Kunststoff- und Recyclingtechnik, Universität Kassel, Kassel, Germany

Poly(lactic acid) (PLA) represents a new group of thermoplastics obtained from renewable raw materials (RRM). PLA properties make it suitable for various processing methods including thermoforming, injection and extrusion molding. Because of unsatisfied thermo-mechanical properties of PLA, this material until today, didn't establish as technical resin. All those events can be fulfilled through adding of non-polluting reinforced natural fibers (NF) such as man-made cellulose or abaca fiber as well. Man-made cellulose fiber (Cordenka) have been shown to have a high-reinforcing potential in PLA for injection molding applications. They ensure a significant increase in mechanical properties such as tensile/bending strengths and stiffness as well as impact resistance. Abaca is a natural fiber which is in use, because of its high tensile strength, as reinforcement for under-floor-covering in Mercedes A Class. Apply of novel combine molding technologies, such as two-step extrusion coating process and consecutively injection molding, lead to significant improvement of all analyzed values. Through addition of 30 wt% of man-made cellulose, the Charpy impact strength by room temperature (RT) increase up to 370% (!) if compared to native PLA. Tensile strength rise to 130% and stiffness to approximately 175%. Reinforcing with abaca fibers (30 wt%) enhance both E-Modulus and tensile strength to 240% and 120%, respectively. The Charpy impact resistance of PLA/abaca can be improved by the factor 2 (225%). Scanning electron microscopy (SEM) pictures show relatively good adhesion at the fiber/matrix interphase although no coupling agent was used (fibers without any treatment). The fiber orientation after injection molding process is analyzed via optical microscopy.

POSTER 26

The Properties of Bamboo Flour-Plastic Composites with a High Filler Content

Masahiro Takatani, Associate Professor, **Ayako Ishikawa**, **Takashi Sakamoto**, **Kohei Ikeda**, Graduate Students, and **Tadashi Okamoto**, Professor, Faculty of Agriculture, Kin-ki Daigaku University, Nara-shi, Japan

Bamboo causes an environmental problem between other plants because of its big propagative power in the growth place in Japan. Therefore, we tried to make a bamboo-plastic composite as one of the effective uses of bamboo materials in many aspects. The properties of bamboo flour-plastic composites with 80% filler contents were examined using waste bamboo flour, polypropylene (PP), and maleic anhydride-modified polypropylene (MAPP) and/or polytetrafluoroethylene (PTFE) as a lignocellulosic material, a thermoplastic polymer, and a compatibilizer, respectively. The compounds were manufactured using a Henschel type mixer, and then the composite boards were molded by a hot platen and a conical twin-screw extruder. The bending fracture strength and water resistance of composites were evaluated. The composite boards made by compression molding and extrusion molding showed good fracture strengths and water resistance by the addition of compatibilizer. The extruded composites showed better fracture strengths and water resistance than the composites made by compression molding. The mechanical properties of boards made by extrusion molding showed a good performance with the following ratio; bamboo flour:PP:MAPP=80:20:2, namely bending fracture strength; 74MPa, and thickness swelling (TS) after 24 hr immersion in water; 1%. A color of composites thickened by addition of an additive more. The composites took on luster and smoothness with the addition of PTFE.

POSTER 27

Extrusion and Compression Molding of Wood/Polylactic Acid Composite with High Filler Content

Kohei Ikeda, Graduate Student, **Masahiro Takatani**, Associate Professor, **Kei Sakamoto**, Graduate Student, and **Tadashi Okamoto**, Professor, Faculty of Agriculture, Kin-ki Daigaku University, Nara-shi, Japan

Preparation of all bio-based composite was examined from wood flour (C-300) and polylactic acid (PL002, PL022, Lacea M-151SQ04, M-151SQ52) used as major components, especially focusing on composite of high-filler content of wood/PLA=80/20 and effect of addition of cellulose esters as compatibilizer or component. Components were mixed with a Henschel type mixer and molded with a hot-press or a conical twin-screw extruder. Properties of products were analyzed by bending and water resistance tests. The effect of additives to the product properties was examined with MAPP (Toyotack M300, H-1100), Metablen A300, and cellulose esters of C2-C6, C12 (average degree of substitution 2.4-2.8). With compression molding, the mechanical strength (MOR) of product prepared in the presence of 2% of MAPP was around 20MPa, and water absorption (weight gain) in water at room temperature in 24 hr was poor (30-65% increase). However, by extrusion molding, corresponding MOR increased to 40-50 MPa and water absorption was lower than 10%, which satisfied Japanese Industrial Standard A5741. However, the positive effect of addition of MAPP was not as significant as is well known with wood/polypropylene composite. When cellulose ester was added, the product composite showed a positive effect on MOR by compression molding, and the effect reached the maximum at 6% of addition (MOR, 30 MPa), although water absorption was still high at around 40%. When analyzing the effect of the addition of 2% of cellulose esters with higher carboxylic acids of more than 2 carbons, MOR of compression molded product increased with increase of carbon numbers of ester, and reached the maximum around C4-C5 and decreased rapidly with C5 and C6. Again, water absorption is not improved very much. One of the reasons of this tendency is assumed to be the miscibility of cellulose esters with PLA matrix. Although the water resistance of composite was not sufficient with compression molding, JIS A5741 standard of 10% increase in the weight after 24 hr immersion in water at room temperature was cleared when more than 40% of wood flour was replaced by cellulose acetate (DS, 2.4). At that time, MOR was 30-40 MPa and cleared the JIS standard. Thus, all bio-based composite of reasonable property was prepared from wood/PLA.

POSTER 28

Mechanical Properties of Lyocell Fibers and their Adhesion with Thermoplastic Matrices

Ramesh-Babu Adusumalli, Ph.D. Student, and **Moritz Reifferscheid**, Research Assistant, Department of Materials Science & Process Engineering, BOKU-University of Natural Resources & Applied Life Sciences, Vienna, Austria; **Hedda Weber**, Area Manager, Wood Chemistry, Kompetenzzentrum Holz GmbH, Linz, Austria; **Thomas Roeder**, Wood Chemist, and **Herbert Sixta**, Associate Professor, Lenzing R&D, Lenzing, Austria; and **Wolfgang Gindl**, Associate Professor, Department of Materials Science & Process Engineering, BOKU-University of Natural Resources & Applied Life Sciences, Vienna, Austria

Three different kinds of regenerated cellulose fibers, viscose, modal, and lyocell were subjected to single fiber tensile tests in order to determine the modulus of elasticity (MOE), tensile strength, and failure strain. The results were compared to glass fibers and flax fibers. With regard to their MOE and tensile strength, regenerated cellulose fibers showed clearly lower values than glass fibers, even when their low density was taken into account. The average MOE and tensile strength of regenerated cellulose fibers was also lower than the values measured for flax fibers, but when variability was considered, both fibers performed similarly. In terms of interfacial shear strength with PP and HDPE, lyocell and flax fibers performed less well than sized glass fiber. The most important difference between regenerated cellulose fibers and both glass and flax fibers is their high failure strain and thus, high work to fracture. The high work to fracture of regenerated cellulose fibers makes them particularly useful for composite applications where high fracture toughness is required.

POSTER 29

Development of a Wood Fiber Panel Product Containing Polypropylene/Polyester Bicomponent Fiber

Herman van Dyk, Research Assistant, and **Perry Peralta**, Associate Professor, Department of Wood & Paper Science, North Carolina State University, Raleigh, North Carolina, USA

The feasibility of manufacturing engineered wood composites with nonwoven textile technology was investigated. Recently, technology has evolved for combining wood fibers with plastics to make panel products. Polypropylene and polyethylene is most commonly used due to cost, ease of processing, and compatibility with wood fibers. Attempts have been made to incorporate stronger polymer fibers into a wood product, but these have been limited by problems associated with wood fiber and polymer adhesion. Fibers from polymer blends have been increasingly used to modify the physical properties of fabrics. These bicomponent fibers consist of at least two components, running parallel in the fiber throughout the length. Each of the components of the fiber retains its own characteristic properties. Bicomponent fibers are classified as side-by-side, sheath core, and sea-island. With sheath-core fibers, the core component is completely surrounded by the sheath component. The sheath component has areas of interaction with the core and the surrounding medium. Commonly, the sheath polymer has a lower melting temperature than the core. During heating, the sheath will melt and diffuse through the surrounding fibers, acting as a binder. This study focused on the development of a wood / bicomponent fiber composite panel. A polypropylene / polyester bicomponent fiber was blended in (10, 30, and 50% by weight) with the wood fiber prior to the application of resin. The panels were pressed to 12.5 mm at 177°C for 3 minutes. The polypropylene sheath of the bicomponent fiber melts at 168°C, leaving the polyester core intact. The panels were tested and compared to MDF manufactured using the same process parameters. Significant improvements were seen in both physical and mechanical properties of the panels containing the bicomponent fibers.

POSTER 30

A Unique Fungicide for Wood-Filled Plastic

William B. Woods, Manager, Business Development, Industrial Biocides, International Specialty Products, Inc., Wayne, New Jersey, USA

The agrichemical folpet is shown to be an effective fungicide for use in a broad range of plastics including wood-filled plastics. Performance is evaluated through a tiered product development program utilizing: 1) Petri dish and environmental chamber accelerated laboratory testing of weathered samples; and 2) Exterior exposure of panels or full-scale constructs (e.g., test decks). The mechanism of action of folpet, a trichloromethylthio-adduct, trichloromethylthio-phthalimide, is discussed. The folpet active ingredient is additionally compounded (formulated) into several physical forms that include resin and lubricant carried pellet concentrates; granules and liquid dispersion and solution forms for ease of processing into plastics and wood-filled plastic composites based on polyolefins; PVC and other resins. Data is presented that demonstrates protection from defacement and deterioration by mildew as well as wood-rot fungi at use-levels of 0.05 to 0.5% and treatment costs of cents per board-foot of composite without significant impact on physical properties. Thermostability data are presented and stability enhancement through the addition of stabilizers is discussed. Air monitoring during extrusion operations shows that folpet-based products are easily handled safely in the work environment. A manufacturing case study is presented.

POSTER 31

A Moisture Diffusion Model for Natural Fiber-Reinforced Composites

Yibin (Anna) Xue, Assistant Research Professor, and **Kungpeng Wang**, Graduate Student, Center for Advanced Vehicular Systems, Mississippi State University, Starkville, Mississippi, USA; **Hongwu Zhang**, Professor, Department of Applied Mechanics, Dalian University of Technology, Dalian, P.R. China; and **Mark Horstemeyer**, Professor, Center for Advanced Vehicular Systems, Mississippi State University, Starkville, Mississippi, USA

Natural fibers are gaining increased use as reinforcement in plastics for automotive applications, attributable to their superior low density and high specific strength. The primary disadvantage of cellulose-based natural fibers is their tendency to absorb water and swell. This

inevitably leads to undesired dimensional instability of the composite and to the arising of additional loading in constraint geometry. A measure of the hygroexpansion, or water adsorption behavior of the fibers could serve to rank the suitability of different kinds of cellulosic fibers with regard to dimensionally stable composites. A typical quick and simple water adsorption standard for natural fiber-reinforced composites has been developed for automotive applications (i.e., submerging the composite into water for a short period of time and the amount of weight-gain should be less than the specified value). To understand the water or moisture adsorption mechanism of composite, room-temperature moisture-saturated composites, of natural fiber weight of 0, 20, 30, 40, 60%, were conditioned in a low-pressure dehumidification environment. Weight losses were measured daily. The measured functional relationship between weight-loss and time was found compliant to the Fick's law of diffusion. Thus, a micromechanical-based model was developed to simulate the moisture diffusion in the composite with various natural fiber fractions. The fiber and matrix are assumed to be homogeneous, but the fiber is anisotropic in moisture diffusion. The fiber is randomly distributed in the representative volume element with or without preferred orientation. A statistically distributed interfacial diffusion property is assumed because of difficulty in measurement. It is our hope that the diffusion model for natural fiber composites may lead to optimization in the composite design.

POSTER 32

Flexural Fatigue Properties and Cumulative Damage Model Verification of Wood Flour-Polypropylene Composites

Han-Seung Yang, Research Associate, and **Michael P. Wolcott**, Professor, Composite Materials Engineering/Adhesion and Research Director, Wood Materials & Engineering Laboratory, Washington State University, Pullman, Washington, USA

Wood and natural lignocellulosic material-filled thermoplastic polymer composites have been widely researched and used due to their abilities to combine the favorable performance and low-cost attributes of both lignocellulosic materials and thermoplastic polymers. Among the synthetic thermoplastic polymers, polyolefin have several good properties such as various applications, excellent chemical resistance, good mechanical properties, and low cost. These bio-composites can be used as house wares, car interior such as dashboard, and various building materials. Such natural lignocellulosic filler-reinforced thermoplastic polymer composites can be used as an alternative to preservative-treated timber in both residential and commercial applications. In many cases of pedestrian and transportation structures, repeated loading causes failure of the material. Small-sized coupon samples of wood flour-polypropylene composites were tested in flexural fatigue to avoid internal heating during cyclic loading and follow-up previous research of the mechanical durability. In this research, the influences of environmental temperature condition and stress ratio on the fatigue life were investigated. The frequency of 10-Hz was tested at 45-80% of the ultimate stress. Fatigue life decreased with increasing stress ratio, but the strain to failure remained reasonably constant. Fatigue life also decreased with decreasing environmental temperature condition because the glassy and brittle property of the matrix polymer in lower temperature region. Applied stress ratio-life cycle (S-N) data were collected to apply stress ratio-fatigue life plot between 45 and 80% at 10-Hz. Cumulative damage model was verified using experimental data to describe damage growth in terms of material constants, stress ratio, and environmental temperature.

POSTER 33

High-Performance Composites made from Cellulose Nanofibers

Eng Hau (Patrick) Qua, Ph.D. Student, and **Peter Hornsby**, Professor, School of Mechanical & Aerospace Engineering, Queen's University, Belfast, United Kingdom

The primary objective of the research is to establish an optimum method for preparing cellulose nanowhiskers (CNW) as reinforcing fillers for polymers. Various methods have been applied in an attempt to yield CNW including modification using solvents, ultrasound, and supercritical carbon dioxide. Products from these treatments have been characterized by TEM, SEM, and optical microscopy. The enhancement in mechanical properties resulting from inclusion of these reinforcements in polymers will be discussed in relation to conventional natural fiber-reinforced polymer composites.

POSTER 34

Adhesive Penetration of Wood Cell Walls by Scanning Thermal Microscopy

Johannes Konnerth, Ph.D. Student, Department of Materials Science & Process Engineering, BOKU-University of Natural Resources & Applied Life Sciences, Vienna, Austria; **Timothy G. Rials**, Professor and Director, **David P. Harper**, Assistant Professor, and **Seung-Hwan Lee**, Post-Doctoral Research Associate, Tennessee Forest Products Center, University of Tennessee, Knoxville, Tennessee, USA; and **Wolfgang Gindl**, Associate Professor, Department of Materials Science & Process Engineering, BOKU-University of Natural Resources & Applied Life Sciences, Vienna, Austria

Scanning thermal microscopy (SThM) was used on cross sections of wood adhesive bonds with the aim of studying the distribution of adhesive in the bond line region. The distribution of thermal conductivity as well as temperature in the bond line area was measured on the surface by means of a nanofabricated thermal probe offering high spatial and thermal resolution. Both the thermal conductivity and the surface temperature were found suitable to identify different materials in the bond region (i.e. adhesive, wood cell walls, and embedding epoxy). The results of the SThM study clearly demonstrate that polyurethane adhesive did not cause changes of thermal properties in wood cell walls with adhesive contact. By contrast, cell walls adjacent to phenol-resorcinol-formaldehyde adhesive showed distinctly changed thermal properties, which is attributed to the presence of adhesive in the wood cell wall.

POSTER 35

A Six Sigma Approach to Scale-Up and Transferring of Wood-Fiber Composite Processes

Keith J. Effertz, Project Manager, and **Scott Koenig**, Business Operations Manager, Aspen Research Corporation, White Bear Lake, Minnesota, USA

Transferring and scale-up of any process can be challenging; they are even more challenging when raw material supplies differ due to cost and/or logistical reasons. With circumstances like these, there are always assumptions that need to be verified. This paper will describe a systematic approach using Six Sigma to help mitigate / reduce the potential risk(s) of transferring this technology; specifically it will describe potential processing and performance risks for transferring a wood fiber composite process.

POSTER 36

Understanding Process and Material Interaction of a Foamed Wood-Fiber Composite

Keith J. Effertz, Project Manager, Aspen Research Corporation, White Bear Lake, Minnesota, USA

This presentation will discuss a methodology for understanding the interactions between process and the materials chosen in order to foam a wood fiber composite. Specifically, this paper will discuss the use of a design of experiments (DOE) to understand the relationship of process and material variables that can vary the bulk density of the product; leading to differences in performance or end use applications.

POSTER 37

Using a Systematic Approach to Converting Batch to Continuous Processing

Keith J. Effertz, Project Manager, Aspen Research Corporation, White Bear Lake, Minnesota, USA

This presentation will discuss a methodology for converting traditional batch processing into continuous manufacturing that achieves process flexibility, overall yield, and superior product quality. Several examples will be used and the benefits of both processing methods reviewed.

POSTER 38

Incorporation of Animal Manures as Reinforcing Fillers in HDPE and HDPP

Roger M. Rowell, Professor, Department of Biological Systems Engineering, University of Wisconsin, and Pioneering Scientist, USDA Forest Products Laboratory, Madison, Wisconsin, USA; **Eric L. O'Neill** and **Andrzej Krzysik**, Forest Products Technologists, USDA Forest Products Laboratory, Madison, Wisconsin, USA; and **David Bossman** and **Dale F. Gallaway**, Principles, PNC Products, LLC, St. Louis, Missouri, USA

Animal agriculture is under increasing pressure to produce more and more meat, milk, and eggs giving rise to an increasing amount of manures. In the past, manures have been viewed as a waste byproduct used mainly as a fertilizer that has a value of 2 to 4 cents per dry pound. We need to change our view of manures from waste to asset. Destroying manures by burning or lagooning may solve the environmental problem, but it does nothing to add to animal income. One of the alternatives is to use animal manures in industrial products. Based on past research at the Forest Products Laboratory in the area of wood and agricultural flours and fibers as fillers in thermoplastics, this research program uses swine and cow manures as reinforcing fillers in HDPE and HDPP. This is a win-win situation as it increases the value of the animal manures, decreases the cost, and improves mechanical properties of the thermoplastic composites. Swine manure solids are collected using a flocculation process removing over 95% of the manure solids. The solids are dried, mixed with cotton-mill byproducts, and composted for 30 days. The composted resource is then compounded with either HDPE or HDPP at different levels with and without a compatibilizer. A 40% blend of swine manure with HDPE and 2% MAPE gives a composite with MOE in bending of 1.31 GPa and MOR of 34.7 MPa as compared to unfilled HDPE MOE of 0.75 GPa and MOR of 15.1 MPa. A mixture of dried cow manure with straw bedding (40% with 2% MAPE) direct from the University of Wisconsin Experimental Farms, compounded with HDPE gives MOE in bending of 2.18 GPa and MOR 21.9 MPa as compared to 40% pine flour with 2% MAPE MOE 2.98 and MOR 33.4 MPa. Data on other mixtures of swine and cow manures in HDPE and HDPP will be presented in the poster.

POSTER 39

Poly lactide/Pine Wood Flour Composites

Srikanth Pilla, Graduate Student, and **Shaoqin (Sarah) Gong**, Assistant Professor, Department of Mechanical Engineering, University of Wisconsin, Milwaukee, Wisconsin, USA; **Eric L. O'Neill**, Forest Products Technologist, USDA Forest Products Laboratory, Madison, Wisconsin, USA; **Roger M. Rowell**, Professor, Department of Biological Systems Engineering, University of Wisconsin, and Pioneering Scientist, USDA Forest Products Laboratory, Madison, Wisconsin, USA; and **Andrzej Krzysik**, Forest Products Technologist, USDA Forest Products Laboratory, Madison, Wisconsin, USA

Bio-based and biodegradable polylactide (PLA)/pine wood flour (PWF) composites were investigated as a means to reduce the overall material cost. The composites were prepared using a Kinetic-mixer (K-mixer) and an injection molding machine. The static mechanical properties were measured using Instron tensile testing machine. The tensile modulus increased with the PWF content whereas the toughness and strain-at-break decreased. The tensile strength remained the same irrespective of the PWF content (up to 40%). The dynamic mechanical properties were investigated using dynamic mechanical analyzer. The storage modulus increased with the PWF content, which is in agreement with the tensile modulus. Additionally, the specimens that have PWF treated with silane showed higher storage modulus than the ones without silane. The area integration underneath the $\tan\delta$ peaks obtained from the dynamic mechanical analysis decreased with increasing PWF indicating that the PLA/PWF composites exhibited more elastic behavior with increasing PWF. The crystallization effects have been studied using differential scanning calorimetry. The degree of crystallinity is found to increase significantly with the PWF content. Furthermore, the pre-treatment of PWF with silane is found to have positive effect on its nucleating ability as pre-treated PLA/PWF composites showed higher crystallinity compared with non-treated counterparts. The morphology of fractured surfaces of PLA/PWF composites has been studied using scanning electron microscope. Finally, a Halpin-Tsai analytical model to predict Young's modulus of PLA-PWF

composites has been presented to compare the theoretical results with that of experimental ones.

POSTER 40

Preliminary Assessment of WPC Durability Behaviors Using Mechanical Properties and Water Immersion

Warren J. Grigsby, Senior Scientist, **Stephanie Weal**, Scientist, and **Eshan Nasheri**, Student Intern, Biomaterials Engineering Group, Scion, Rotorua, New Zealand

Due to their nature, wood-plastic composites (WPC) are susceptible to the environmental conditions of weathering. This can affect the durability of the product and shorten its in-service life. As with wood and wood product durability, a loss in mechanical performance often results prior to a measurable weight loss and it might be anticipated such changes also occur in WPC. We have been investigating the adaptability of dynamic mechanical analysis (DMA) to measure real-time changes in mechanical performance on WPC immersion in water. A preliminary method has established the trend in DMA performance was comparable with the resulting mechanical properties of water soaked samples. Reported are results analyzing a combination of polypropylene and poly(lactic acid) samples prepared with either wood flour, wood fiber, or acetylated wood fiber.

POSTER 41

Improvement on Mechanical and Environmental Properties of Kenaf-Reinforced Polypropylene Composites

Sharifah Hanisah S.A. Aziz, Research Officer, and **Khairul M.D. Zaman**, Director, Radiation Processing Technology Division, Malaysian Institute for Nuclear Technology Research, Selangor, Malaysia; and **Jalaluddin Harun**, Director, Institute of Tropical Forestry & Forest Products, Universiti Putra Malaysia, Selangor, Malaysia

At present, research in composite materials is being directed at using natural fibers instead of synthetic fibers. Kenaf, which is extensively grown in the Far East including Malaysia, has been identified as a bast (stem) fiber with significant market potential. In this work, long and random kenaf fibers were used in the as-received condition and alkalinized with a 0.06M NaOH solution. They were combined with polypropylene thin sheets, sandwiched between layers of kenaf fibers and hot-pressed to form natural fiber composites. The mechanical properties of the composites were investigated to observe the effect of fiber alignment, fiber treatment, and pre-irradiation method used. A general trend was observed whereby alkalinized and long fiber composites gave higher flexural modulus and flexural strength compared with random mat and untreated fibers. The long fiber composites also gave a higher work of fracture. However, the correlation between fiber surface treatment and the work of fracture was less clear. Pre-irradiation on the polypropylene pellets and fibers before the composite is manufactured showed significant improvement on the flexural modulus and flexural strength. The bond performance test performed on the treated composites demonstrated good bonding and interfacial adhesion between the fiber and matrix. However, the method of molding used need to be improved to optimize the performance of the composites.

POSTER 42

Rheology of Injection Molded Oil Palm Empty Fruit Bunch Fibers – Polypropylene Composites: Effects of Electron Beam Processing

Khairul M.D. Zaman, Director, Radiation Processing Technology Division, Malaysian Institute for Nuclear Technology Research, Selangor, Malaysia; and **Khalina Abdan**, Head, Biocomposite Technology Laboratory, and **Jalaluddin Harun**, Director, Institute of Tropical Forestry & Forest Products, Universiti Putra Malaysia, Selangor, Malaysia

In this study, polypropylene (PP) and oil palm empty fruit bunch fibers (EFB) were irradiated at 10 kGy using electron accelerator prior to melt mixing to produce composite pellets. Two types of reactive additives that have functional groups of diacrylate and triacrylate were also used for preparing the composite pellets. The composite pellets were then subjected to injection molding for preparation of test pieces for physical, mechanical, and rheology properties study. Haake Rheometer RS 150 was used to study the changes in viscosities of the composites at different shear rates. Viscosity change is one of the important parameters in plastic processing, in particular, is relation to the shear rates

for injection molding and extrusion processes. The melt flows of the composites were also measured to complement and confirm the rheology behavior of the composites. The PP melts showed pseudoplastic behavior and the viscosity was constant at low shear rate and begun to decrease at 5s^{-1} shear rate. Upon irradiation, the viscosity of PP decreased due to chain scission and the sudden drop of viscosity at high shear rate was not significant. The presence of EFB fiber in the PP matrix interrupted the flow ability of PP that cause viscosity to increase. Upon irradiation of EFB/PP, the viscosity of the composites decreases. This indicates that no crosslinking occurs between EFB and PP during melt mixing although PP and EFB active radicals were present in the composites. However, by adding di- and tri-functional acrylates, the viscosity of the irradiated EFB/PP increases significantly. This study showed that di- and tri-functional acrylates play important roles in providing the bridge for a three-dimensional network to be formed between EFB and PP. These results were further confirmed by the melt flow measurement of irradiated EFB/PP and irradiated EFB/PP with the reactive additives. In this paper, rheology behavior of electron beam irradiated EFB/PP composites were also compared with maleated PP/EFB composites.

POSTER 43

Mechanical and Thermal Properties of the Thermoplastics Reinforced with Natural Fibers Processed by Electron Beam

Sok Won Kim, Professor, Department of Physics, University of Ulsan, Ulsan, South Korea; and **Seungmin Oh** and **Kyusee Lee**, Ilkwang Co., Ltd., Ulju-gun, South Korea

Thermoplastics reinforced with natural fibers, jute, kenaf, flax, etc. have great potential for wide applications in many fields because of their reasonable price, light weight, high formability, superior elasticity, and high recycling probability. Regardless of the many advantages, one shortcoming is the deformation after the forming in high temperature of about 200°C caused by the poor adhesion between the natural fibers and thermoplastics. Also, the energy saving in connection with car air-conditioning becomes very important; thus, the study of mechanical and thermal properties by the chemical reactions and micro-damages in the surfaces caused by the radiation of electron beam became momentous. In this study, the thermal conductivity and tensile strength of several kinds of thermoplastic composite boards composed with polypropylene (PP), natural fiber (NF), and coupling agents were processed by the electron beam (energy: 10 keV, dose: 0~20 kGy). The length and thickness of PP and NF are 80 ± 10 mm and $40\text{-}120$ μm , respectively. The results show that the thermal conductivity and the tensile strength were improved by increasing the energy and dose of the electron beam and they were explained by the SEM photograph of the samples. These results will be utilized as the data for the energy savings in automobiles with the relation of cooling and heating in harsh environment.



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