

<b>CONFERENCE PROGRAMME</b>	<b>4</b>
<b>SPEAKER ABSTRACTS</b>	<b>6</b>
CONFERENCE OPENING CEREMONIES	6
TOPIC 1: CURRENT/FUTURE LIMITATIONS OF PLANT FIBRES IN INDUSTRIAL PRODUCTS	7
LUNCH ADDRESS	9
TOPIC 2: NEW DESIGN OPPORTUNITIES FOR PLANT FIBRE PRODUCTS	10
TOPIC 3: REALISING THE FULL PERFORMANCE POTENTIAL OF PLANT FIBRES	12
TOPIC 4: THE FUTURE / NEXT STEPS	14
SUMMARY AND CONCLUSIONS	16
<b>BIOGRAPHIES OF CHAIRPERSONS AND SPEAKERS</b>	<b>22</b>
<b>LIST OF PARTICIPANTS</b>	<b>28</b>
<b>POSTER ABSTRACTS</b>	<b>31</b>
P1. COUPLING OF PHENOLS TO LIGNIN IN PULP FIBRES AND POTENTIAL USE OF THE FIBRE PRODUCT	31
P2. PRESS CONSOLIDATION OF COMPOSITES WITH THERMOPLASTIC POLYMERIC MATRICES	32
P3. FILAMENT WINDING OF COMPOSITES AT RISØ NATIONAL LABORATORY, DENMARK	33
P4. NATURAL FIBRE COMPOSITES: COMPACTION OF MATS, PRESS CONSOLIDATION AND MAT. QUALITY	34
P5. AUTOCLAVE CONSOLIDATION OF COMPOSITES AT RISØ NATIONAL LABORATORY, DENMARK	35
P6. LIGNIN AS NATURAL BINDER	36
P7. CULTIVATION AND ENZYMATIC RETTING OF FLAX IN GEOTHERMAL WATER IN ICELAND.....	37
P8. FIBRES AS FILTERS FOR WASTEWATER TREATMENT	38
P9. TRIALS WITH HEMP FOR FIBER PRODUCTION DENMARK 1998	39
P10. DETERMINATION OF DENSITY, POROSITY, FIBRE AND MOISTURE CONTENT IN PLANT FIBRE COMPO..	40
P11. EVALUATION OF COMPOSITE MATERIAL QUALITY BY MICROSCOPY	41
P12. INDUSTRIAL CROPS IN DENMARK – ECONOMY AND MARKET POTENTIALS .....	42
P13. MISCANTHUS PROPAGATION MATERIAL SUPPLY AND END USE DEVELOPMENT	43
P14. PLANT FIBRE MORPHOLOGY AND SURFACE CHARACTERISTICS OBSERVED BY SCANNING EM	44
P16. IMPROVEMENT OF APPLICABILITY OF POTATO STARCH AS NON-FOOD RAW MATERIAL	45
P17. COMPOSITES MADE FROM BIOPOLYMERS AND NATURAL FIBERS	46
P18. LONG PLANT FIBRES FOR MANUFACTURING OF REINFORCED INDUSTRIAL PRODUCTS	47
P19. BIOLOGICALLY BASED PACKAGING MATERIALS FOR FOODS	48
P20. THE CHARACTERISATION AND MODIFICATION OF WOOD AND PLANT FIBRES	49
P21. FAIR 1697: VALIDATION OF RAW MATERIAL COMING FROM KENAF	50
P22. FIBRES FROM FLAX AND HEMP FOR MAT-PRODUCTION SPECIALLY INSULATION PURPOSES	51
P23. GEOMETRICALLY MODIFIED BIO-FIBERS THROUGH ENZYME TREATMENT	52
P24. QUANTITATIVE NON-DESTRUCTIVE CHARACTERISATION (NDC) OF PLANT FIBRE COMPOSITES	53
P25. PHYSICAL PROPERTIES OF LINSEED ( <i>LINUM USITATISSIMUM</i> L.) FIBRES	54
P26. PROPERTIES OF WHEAT STRAW AND BEECHWOOD FIBRE FRACTION PREPARED BY WET OXIDATION...	55
P27. AIR 3-CT94-2000: HIGH-PERFORMANCE BIOCOMPOSITES WITH IMPROVED DURABILITY AND DIMENSIONAL STABILITY FROM NON-TOXIC CHEMICALLY MODIFIED LIGNOCELLULOSIC FIBRES	56
P28. DEVELOPMENT OF A NEW COATED MEMBRANE TEXTILE USING NATURAL PLANT FIBRES	57
P29. CONVERSION OF PLANT RESIDUES TO HIGH-VALUE PRODUCTS	58
P30. WET-OXIDISED WHEAT STRAW USED AS REINFORCEMENT FOR POLYPROPYLENE COMPOSITES	59
P31. MECHANICAL CHARACTERISATION OF PLANT FIBRE COMPOSITES	60
P32. FIBRE STIFFNESS AND STRENGTH ESTIMATED FROM TESTS ON COMPOSITES	61
P33. OPTIMISATION OF THE AGROFIBRE QUALITY BY AN INNOVATIVE BIOTECHNOLOGICAL APPROACH	62
P34. A ROUTE FOR THE MANUFACTURE OF BIODEGRADABLE COMPOSITES FROM RENEW. RES.MATERIALS	63



---

## ***Conference Programme***



Photographer for H.M. The Queen  
Rigmor Mydtskov

The conference is under the patronage of **His Royal Highness Prince Joachim of Denmark**. Prince Joachim of Denmark is a dedicated large-scale farmer with a strong interest in diversification of agriculture.

---

**Thursday 27 May 1999**

**CONFERENCE OPENING CEREMONIES**

- 9.00-9.05 *Mr Finn Rexen* - Head of Division, Danish Directorate for Development, Ministry of Food, Agriculture and Fisheries, Copenhagen, Denmark
- 9.05-9.15 *Dr Bent Schmidt-Nielsen* - Vice Chancellor, The Royal Veterinary and Agricultural University, Frederiksberg, Denmark
- 9.15-9.25 *Mr Flemming Duus-Mathiesen* - Director General, Research and Development, Danish Directorate for Development, Ministry of Food, Agriculture and Fisheries, Copenhagen, Denmark
- 9.25-9.35 **Welcome by Conference Chairman.** *Dr Roger Rowell* - Project Leader, Modified Lignocellulosic Materials, USDA Forest Products Laboratory, Madison, USA
- 9.35-10.00 **Perspectives on the performance of natural plant fibres.**  
*Dr Per Ole Olesen* - Head of Centre, Centre for Plant Fibre Technology and Professor, The Royal Veterinary and Agricultural University, Taastrup, Denmark

**TOPIC 1: CURRENT/FUTURE USES AND LIMITATIONS OF PLANT FIBRES IN INDUSTRIAL PRODUCTS**

Topic Chairman: *Professor Rudolf Kessler* - Director, Institut für Angewandte Forschung, Reutlingen, Germany

- 10.00-10.30 **Renewable materials for automotive applications.** *Dr Thomas Schuh* – Manager, Polymer & Composite Application Daimler-Chrysler AG, Stuttgart, Germany
- 10.30-10.45 **Coffee Break**
- 10.45-11.15 **High performance applications of plant fibres in aerospace and related industries.** *Dr Axel Herrmann* - Head of Structure Technology, Deutsche Zentrum für Luft- und Raumfahrt e.V., Braunschweig, Germany
- 11.15-11.45 **Plant fibre supply - Opportunities and current limitations.** *Mr Gary Newman* - Director, JB Plant Fibres, Bangor, Great Britain
- 11.45-12.15 **Panel Discussion**
- 12.15-13.30 **Lunch and lunch address**  
**Green fibres - Present state and future prospects for the next millennium.** *Dr Ryszard Kozłowski* - Director, Institute of Natural Fibres, Poznan, Poland

**TOPIC 2: NEW DESIGN OPPORTUNITIES FOR PLANT FIBRE PRODUCTS**

Topic Chairman: *Mr Lars Thøgersen* - Director, CPH Industriel Design, Copenhagen, Denmark

- 13.30-14.00 **Influence of fibre properties on bio-composite design and performance.** *Dr Laurence Mott* – Research Manager, Perstorp A/B, Perstorp, Sweden
- 14.00-14.30 **Design potential of plant fibres.** *Mr Jorn E. Behage* - Managing Director, Proterra, Wageningen, The Netherlands
- 14.30-15.00 **Exploring the limits of design: Potential in plant fibre products.** *Dr Roger Rowell* - Project Leader, Modified Lignocellulosic Materials, USDA Forest Products Laboratory, Madison, USA
- 15.00-15.30 **Panel Discussion**
- 15.30-15.45 **Coffee Break**

**TOPIC 3: REALISING THE FULL PERFORMANCE POTENTIAL OF PLANT FIBRES**

Topic Chairman: *Dr Laurence Mott* - Research Manager, Perstorp A/B, Perstorp, Sweden

- 
- 15.45-16.15 **Optimization of methods of fibre preparation from agricultural raw materials.** *Dr Jan E.G. van Dam* - Senior Researcher, Department of Fibres and Cellulose, Agrotechnological Research Institute, (ATO-DLO), Wageningen, The Netherlands
- 16.15-16.45 **Improvement of fibre performance in composites and related materials.** *Dr Mark Lawther* - Professor, The Royal Veterinary and Agricultural University, Taastrup, Denmark
- 16.45-17.15 **Tailoring product manufacturing processes to optimise the performance of plant fibres.** *Dr Jamie Hague* - Deputy Director, The BioComposites Centre, University of Wales, Bangor, United Kingdom
- 17.15-17.45 **EU-financed research on non-traditional industrial uses of biological fibres: Past projects and future plans.** *Dr Johannes Klumpers* – European Commission, DGXII.E.2, Life Sciences, Brussels, Belgium
- 19.00- **Conference Banquet**

## **Friday 28 May 1999**

### **TOPIC 4: THE FUTURE / NEXT STEPS**

Topic Chairman: *Dr David Plackett* - Visiting Professor, The Royal Veterinary and Agricultural University, Taastrup, Denmark

- 8.30-9.00 **Green Cotton – an example of plant fibres in a sustainable development.** *Mr Leif Nørgaard* - Managing Director, Novotex A/S, Ikast, Denmark
- 9.00-9.30 **Strategy for a sustainable future of fibre plants.** *Professor Rudolf Kessler* - Director, Institut für Angewandte Forschung, Reutlingen, Germany
- 9.30-9.45 **Coffee Break**
- 9.45-10.15 **Perspectives on the utilisation of natural binders in composite materials.** *Dr Claus Felby* - Research Scientist, Novo Nordisk A/S, Bagsværd, Denmark
- 10.15-10.45 **Scenarios on the future of consumer attitudes and their use of sustainable products.** *Mrs Ute von Reibnitz* - Scenarios+Vision, Vence, France
- 10.45-11.15 **Panel Discussion**

### **RECOMMENDATIONS AND CLOSING REMARKS**

- 11.15-11.35 *Mr Melvyn Askew* - Chairman, Interactive European Network for Industrial Crops and their Applications (IENICA), Central Science Laboratory, MAFF, York, Great Britain
- 11.35-11.55 *Dr Roger Rowell* - Project Leader, Modified Lignocellulosic Materials, USDA Forest Products Laboratory, Madison, USA
- 11.55-12.00 *Mr Finn Rexen* - Head of Division, Danish Directorate for Development, Ministry of Food, Agriculture and Fisheries, Copenhagen, Denmark
- 12.00-13.00 **Buffet hosted by Vice Mayor Rikke Hvilshøj, The Town Hall of Frederiksberg**

### **CONFERENCE TOUR**

- 13.00-17.00 Tours to the facilities of two partners in the Centre for Plant Fibre Technology - The Royal Veterinary and Agricultural University, Taastrup and the Risoe National Laboratory, Roskilde.

## **Speaker Abstracts**

### **CONFERENCE OPENING CEREMONIES**

The speakers are Mr Finn Rexen, Dr Bent Schmidt-Nielsen, Mr Flemming Duus-Mathiesen, Dr Roger Rowell and Dr Per Ole Olesen

---

## **Perspectives on the performance of natural plant fibres**

Dr Per Ole Olesen, Head of Centre, The Royal Veterinary and Agricultural University, Taastrup, Denmark

The main characteristics of the most important plant fibres will be described in terms of their microscopic features, ultrastructure, chemical composition and physical properties.

These basic properties can be related to the properties of the end products, which may be divided in three main groups: (1) Mats based on plant fibres for filters, geotextiles and growth media, (2) composites for structural and non-structural purposes, (3) plant fibres as reinforcement in plastic, cement, etc. Perspectives on the use of plant fibres within these three groups will be given.

The aim of the presentation is to give the audience the most basic understanding of plant fiber properties and their variation so as to enhance the understanding of the talks that will follow.

## **Topic 1: Current/Future Uses and Limitations of Plant Fibres in Industrial Products**

**Topic Chairman:** Professor Rudolf Kessler, Director, Institut für Angewandte Forschung, Reutlingen, Germany

### **Renewable materials for automotive applications**

Dr Thomas Schuh, Manager, Polymer & Composite Application, Daimler-Chrysler AG, Stuttgart, Germany

Since the beginning of the nineties, the use of renewable materials for automotive applications has gained a lot of momentum. One of the major reasons is an increased awareness for our environment, often reflected in phrases like protection of resources, CO<sub>2</sub> emission reduction, recycling, and many more.

After natural fibers for automotive applications have been almost completely replaced by their synthetic counterparts, an increasing trend towards using natural materials can be again observed.

Natural fibers like wood, flax, sisal, and cotton can be used for interior parts such as rear decks, pillar and door panels, and dashboard parts. Major highlights beside ecological advantages and process-specific technical properties are the potential to reduce weight, excellent splintering behavior, and an attractive price tag.

One of the downsides of natural fibers is their relatively high water absorption and the accompanying strength reduction and rotting tendency compared to synthetic fibers. These disadvantages are the main reason why natural fibers were mostly used in car interiors without an option for outside applications.

At Daimler-Benz, great efforts were made to activate possible higher material potentials with the goal to replace glass fibers in composites. Another challenge was to find ways for using renewable materials in automotive outside applications. In direct co-operation with material engineers and component developers and in close contact with the suppliers, new material systems were developed and successfully employed for producing parts. Flax fibers specially grown and prepared for technical applications were processed with polypropylene into plates using a technique similar to the GMT process. Subsequently, these plates were processed into finished parts using a hot press. Since it was not possible to reach the same mechanical properties as GMT in all areas, extensive real-world testing was necessary to secure sufficient functioning of all parts.

Due to the positive results, a new composite material system will be introduced into the large-scale production shortly. In this process, natural fibers with unprecedented mechanical properties will be substituted for glass fibers. Moreover, water absorption could be reduced to a level that also allows for outside applications.

This technology will add new perspectives and areas of application for reinforcing plastics with renewable fibers. The motivation for this development was to protect our environment and the ecology system, showing that the effort to manufacture environment-friendly products is more than just a hollow phrase.

High performance applications of plant fibres in aerospace and related industries

Dr.-Ing. A. S. Herrmann (speaker), Dipl.-Chem. U. Riedel, and Dipl.-Ing. J. Nickel, Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Institut für Strukturmechanik, Braunschweig, Germany.

Originally coming from aerospace technology, fibre reinforced plastics (FRP) are successfully used for

---

various applications, today because of their excellent specific properties, e.g., high strength and stiffness, low weight and the potential of optimisation by orientating (especially continuous) fibres along the load paths.

In order to successfully meet the environmental problems of these classic composites, the DLR Institute of Structural Mechanics developed an innovative idea in 1989:

By embedding natural and near natural reinforcing fibres, e.g., flax, hemp, ramie, cellulose, etc., into a biopolymeric matrix from cellulose, starch or lactic acid derivatives, etc. (thermoplastics as well as thermosets), new fibre reinforced materials, called biocomposites, were created and are still being developed. In terms of mechanical properties being comparable to glass fibre reinforced plastics (GFRP), latest developments on new fibre/matrix combinations and environmentally compatible flame retardants enable biocomposites to replace GFRP in most cases. Biocomposites are designed to meet the processing requirements for commonly used manufacturing techniques, e.g., pressing, injection moulding, filament winding, BMC, SMC, etc.

Apart from anisotropic and specially tailored lightweight structural parts with continuous fibre reinforcements, biocomposites are very well suited for panelling elements in cars, railways and aeroplanes, etc., using different kinds of nonwovens from single fibres (needlefelt nonwovens, fleeces, etc.) to be easily adapted to the usually curved shapes of panellings, fairings, etc.

When modifying the resin systems more or less extensively, biocomposites can be designed for different applications either to be stable or biodegradable. Apart from re-use or recycling, this offers additional options of a convenient removal after the end of the lifetime, i.e. combustion of any kind of biocomposites now being carbon dioxide neutral and completely slag-free or biodegradation or composting of the biodegradable kinds of biocomposites. Thus they are fully integrated into natural cycles and can also meet the steadily increasing environmental demands of legislative authorities.

### **High performance applications of plant fibres in aerospace and related industries**

Dr.-Ing. A. S. Herrmann, Dipl.-Chem. U. Riedel, and Dipl.-Ing. J. Nickel, Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Institut für Strukturmechanik, Braunschweig, Germany

Originally coming from aerospace technology, fibre reinforced plastics (FRP) are successfully used for various applications, today because of their excellent specific properties, e.g. high strength and stiffness, low weight and the potential of optimisation by orientating (esp. continuous) fibres along the load paths.

In order to successfully meet the environmental problems of these classic composites, the DLR Institute of Structural Mechanics developed an innovative idea in 1989:

By embedding natural and near natural reinforcing fibres e.g. flax, hemp, ramie, cellulose etc. into a biopolymeric matrix from cellulose, starch or lactic acid derivatives etc. (thermoplastics as well as thermosets), new fibre reinforced materials, called biocomposites, were created and are still being developed. In terms of mechanical properties being comparable to glass fibre reinforced plastics (GFRP), latest developments on new fibre/matrix combinations and environmentally compatible flame retardants enable biocomposites to replace GFRP in most cases. Biocomposites are designed to meet the processing requirements for commonly used manufacturing techniques, e.g. pressing, injection moulding, filament winding, BMC, SMC etc.

Apart from anisotropic and specially tailored lightweight structural parts with continuous fibre reinforcements, biocomposites are very well suited for panelling elements in cars, railways and aeroplanes, etc. using different kinds of nonwovens from single fibres (needlefelt nonwovens, fleeces etc.) to be easily adapted to the usually curved shapes of panellings, fairings etc.

When modifying the resin systems more or less extensively, biocomposites can be designed for different applications either to be stable or biodegradable. Apart from re-use or recycling, this offers additional options of a convenient removal after the end of the lifetime, i.e. combustion of any kind of biocomposites now being carbon dioxide neutral and completely slag-free or biodegradation or composting of the biodegradable kinds of biocomposites. Thus they are fully integrated into natural cycles and can also meet the steadily increasing environmental demands of legislative authorities.

---

## **Plant fibre supply - Opportunities and current limitations**

Mr Gary Newman, Director, JB Plant Fibres, Bangor, Great Britain

This paper presents a user's view of the current market environment for the long vegetable fibres such as hemp and flax. The resurgence of hemp and flax in Europe in the 90's has been driven by agricultural subsidy. This has led to an abundant and low cost resource for the fibre using industries such as woven and nonwoven textiles, paper and other novel materials. The potential for products based on hemp and flax fibres is enormous, with the current environmental concerns with the consumption of other non-renewable, non-biodegradable and high energy industrial feedstocks.

The European industrial fibre industry has progressed rapidly throughout the 90's. Biodegradable matting, insulation and automotive composites are three examples of products based on industrial flax fibres. However, much more must be done before the industry can be considered to be sustainable without subsidy.

Most importantly the technology required to process the straw from field through to fibre needs to be developed further to achieve high throughput and produce clean, consistent fibres whilst minimising yield losses. Also, there is a desperate need to develop a European method of grading these new fibres. Important variables include, fibre length, diameter, shive content, colour and moisture content. Finally, as only 20% of the stem is fibrous, successful fibre processing enterprises require a strategy to efficiently handle and market the remaining 80%.

## **LUNCH ADDRESS**

### **Green fibres - Present state and future prospects for the next millennium**

Dr Ryszard Kozlowsky, Director, Institute of Natural Fibres, Poznan, Poland

Green fibres, flax, cotton and other plants, which have been used from more than 6000 years B.C., presently are and will be the future raw materials not only for the textile industry but for modern ecofriendly composites used in different areas of application like: building materials, particle boards, isolation boards, food, feed and nourishment, friendly cosmetics, medicine and source for other biopolymers. They do not cause any disturbing effects of ecosystem, they can grow in different climatic zones and they recycle the carbon dioxide for the atmosphere of our Earth. Resuscitation of these plants for Europe is very important because they give better agricultural balance in this region and they will reduce a deficit of cellulosic pulp for next millennium when the population will be multiplied up to about 11.6 billion people.

Role of multi-purpose application of bast fibrous plants is growing. What are the future prospects of green fibres and many by-products like: seeds, leaves, woody parts, oil, waxes (extracted fine chemicals) and hemp - essential oils for making beers!

To meet these challenges and chances these raw materials should:

In textiles:

- adapt for modern processing techniques
- develop new, mainly clothing/home furnishing items, biodegradable and geotextiles
- adapt more aggressive marketing of their perfect hygiene/health properties
- gain proper attention of governments, local authorities and international bodies and low/standard markets.

In pulp/paper/viscose areas: where the demand for pulp is expected to rise from current level of 270 mil. ton to 480 mil. ton in the year 2010 the possibilities to process green raw-materials into paper/currency/cellulosic fibres/hygiene products and alike are unlimited.

New processes like Alcell, Milex, like South India Viscose Industries technology for jute processing should be widely applied to provide cellulose, fine chemicals and to limit deforestation risks.

In biocomposites: Fibre plants/flax/hemp/ramie/kenaf/jute/abaca/sisal/coir/curaura are seen as promising lignocellulosic raw materials for different applications. Such end-uses searched today wide and high meet the most important challenges of the years to come like:

- the worldwide need for alternative crops for farmers
- self-sufficiency in raw-materials by regions/countries/communities
- responsibility for environmental safety and forest resources
- social responsibility for communities in need of help and development.

---

Being biodegradable, recyclable these lignocellulosic are proposed, combined with natural resin as steel strong yet of lower density composite material for aircraft wings. Combined with different matrix they provide composites for vehicles, building elements, furniture, machine constructions, insulating materials, gardening/agriculture equipment, tropical housing and even grape holding structures in Australia are made of them.

By-products like flax and hempseed, protein, waxes, fragrances have found diversified applications in:

- food: including antisclerotic and anticarcinogenic food additives,  
cosmetic/body care, medicine, eco-paints, modern eco-linoleum and other products.

According to the results of INF's research some fibre plants have the ability to clean the polluted soil and having allelopathic properties provide organic farming. New products on bast and allied fibre plants base for diversified uses will be developed to provide work places and raise the living standards of rural areas world-wide promoting the growth of agriculture rooted industries. These should result in more sustainable development in social and environmental safety.

## **TOPIC 2: NEW DESIGN OPPORTUNITIES FOR PLANT FIBRE PRODUCTS**

**Topic Chairman:** Mr Lars Thøgersen, Director, CPH Industrial Design, Copenhagen, Denmark

### **Influence of fibre properties on bio-composite design and performance**

Dr Laurence Mott, Research Manager, Perstorp A/B, Perstorp, Sweden

Natural fibre properties, both mechanical and chemical are relatively poorly understood. As a consequence, an adequate understanding of fibre property variability for the purpose of bio-composite design has yet to be attained. This paper will explore the most appropriate composite applications for a range of fibre types. The impact of fibre defects on composite performance and, the influence of fibre type on the composite interface will also be explored. The central theme of this paper will be current fibre selection practice and future of fibre composite design by improved fibre selection.

### **Design potential of plant fibres**

Mr Jorn E. Behage, Managing Director, Proterra, Wageningen, The Netherlands

Plant fibres are becoming interesting alternatives for glass fibre or polyolefin fibres reinforced materials for the production of durable goods and disposables. These so called biocomposites are mainly based on renewable resources. (Bio)composites are made out of:

cellulose fibres (flax, jute, hemp, ramie, etc.), wood, paper, etc.

thermoplastic and thermoset binders based on starch, sugar, cellulose, vegetable oil, or proteins

fillers and dyes

Also synthetic binders and dyes are used in current developments of composites. Many of these components are not biodegradable and in some cases hazardous (phenolic or formaldehyde binders). Cellulose fibres and (Bio)composites have important advantages in the market due to their functional and environmental qualities such as weight savings, low energy balance, and low toxic emissions levels during waste processing. By using processing technologies such as: injection moulding, pultrusion, extrusion, RTM, NMT, BMC, SMC, RRIM and rubber press moulding it is possible to reach interesting results in many applications. Currently (bio)composites are entering the market. The most promising developments are reached in the automotive and the building industry.

Main reasons for the application of cellulose fibres and (bio)composites are:

- Technical properties
- Low material costs
- Low wear of dies during production
- Light weight constructions
- Low emissions at disposal during incineration
- Products with new functional advantages can be developed

- 
- New aesthetic appearances can be developed

Materials based on cellulose plant fibres are showing interesting improvement in the field of strength and moisture resistance. Developments in the field of binders based on renewable raw materials make these improvements possible. Due to this improved properties the production of many durable goods is getting feasible. In the paper industry and the hygiene market the development of pulp, fluff and non-wovens is very encouraging and gives new possibilities for the design of products.

### **Exploring the limits of design: Potential in plant fibre products**

Dr Roger Rowell, Project Leader, USDA Forest Service, Forest Products Laboratory and Departments of Biological Systems Engineering, Forestry and The Engineering Centre for Plasma Aided Manufacturing, University of Wisconsin, Madison, USA

The present wood-based composite industry mainly produces two-dimensional (flat) sheet products. In some cases, these flat sheets are cut into pieces and glued/fastened together to make shaped products such as doors, windows, furniture, packaging, etc. Wood veneers have also been used to form two dimensional, and in some limited cases, three dimensional, designs. Plant fibres can be used as “designer components” to form complex profiles using a moulding press. And, if the final shape can be produced during the primary product step, the secondary manufacturing profits can be realized by the primary composite producer. It is possible to make complex shaped composites directly using fiber mat technologies. Successful application of this technology depends on the development of a fiber mat that will maintain its physical until it is used to form a final product. Fiber mats can be made by physical entanglement (carding), non-woven needling, or thermoplastic fiber melt matrix technologies. During mat formation an adhesive can be added and then a shaped product can be made using a thermopressing step. The adhesive can be a thermoset or a thermoplastic depending on the end product performance properties required. Within certain limits, any size, shape, thickness, and density is possible.

Plant fiber resources are renewable, widely distributed, available locally, mouldable, anisotropic, hydroscopic, recyclable, versatile, non-abrasive, porous, viscoelastic, easily available in many forms, biodegradable, combustible, and reactive. Plant fibres have to aspect ratio, high strength to weight ratio, and have good insulation properties (sound, electrical and thermal). The fiber structure is hollow, laminated, with molecular layers and an integrated matrix. Some might consider part of these properties as problems, such as biodegradable and combustible, but these features provide a means of predictable and programmable disposal not easily achieved with other resources.

Plant fibers can be combined with other resources such as plastics, glass, metals, and synthetics. The objective is to combine two or three materials in such a way that a synergism between the components results in a new material that is much better than the individual components.

---

## **TOPIC 3: REALISING THE FULL PERFORMANCE POTENTIAL OF PLANT FIBRES**

**Topic Chairman:** Dr Laurence Mott, Research Manager, Perstorp A/B, Perstorp, Sweden

### **Optimization of methods of fibre preparation from agricultural raw materials**

Dr Jan E.G. van Dam, Senior Researcher, Department of Fibres and Cellulose, Agrotechnological Research Institute (ATO-DLO), Wageningen, The Netherlands

During the various steps of lignocellulosic fibre production from agricultural raw materials a large number of factors are affecting the final product quality.

For profitable West European agricultural production of non-food crops, and especially fibre crops, it is essential to be competitive with the cheaper produced fibre raw materials from other regions in the world. The availability of bulk quantities of products like jute or sisal and potential large scale production in Eastern Europe of flax or hemp is forcing the agro-industrial production in the EU into a specialised niche market. Traditionally, the flax fibre production in Western Europe for high quality linen has been able to cope with competing imported raw materials, because of its high quality standards. The concentration in the past decades, however, of the conventional linen promotion on the fashionable textile market has increased the dependency of the sector on a strongly fluctuating market segment.

One way for EU agriculture to compete on the world market of lignocellulosic fibres is to supply high quality raw materials with an added value for the user. This can only be obtained when the qualitative aspects have been defined in detail for each specific end-use.

Understanding the relation between the properties of a raw material and its production process is fundamental to the improvement of quality. The different stages of the production process have their influence on the end-product price and performance. The whole chain approach is necessary to be able to see where the most promising improvements can be made at the lowest costs. When for example fineness is an issue for the application of a fibre, genetic improvements may not yield the necessary results, when no adequate fibre extraction technology is available or the end product becomes too expensive for the application. On the other hand, if an efficient fibre processing technology can be developed, which substantially upgrades the fibre quality for a specific end-use, irrespective the variable properties of the input raw material, all the efforts for crop improvement are in vain. So a tailor made solution for each different commercial development for fibre applications should be aimed at.

Much has been achieved the last decade in the exploration of the potential markets for different fibre resources, although a real breakthrough still has to come. As a renewable raw material fibre crops do have strong marketing arguments as 'eco-efficient' products for development of sustainable consumption and production. Diversification of the market for fibre products in automotive industry, geotextiles, building and construction materials, bioenergy, etc., are all in the picture, if the quality control of the agro-industrial production chain has been organised according to ISO-norms and supplies of specified products to industrial buyers can be guaranteed.

In this presentation the several aspects of fibre quality in relation to its utilisation and preparation process will be presented.

### **Improvement of fibre performance in composites and related materials**

Dr Mark Lawther, Professor, The Royal Veterinary and Agricultural University, Taastrup, Denmark

The bast fibres obtained from flax and hemp are inherently strong and offer strength/ weight advantages over synthetic fibres. Flax fibres in particular can, with careful processing, be produced to high quality and fineness. The textile industry has mainly spearheaded developments in this area and most defibration processes are biased towards the effective production of yarns from flax. Until recently, composite manufacturers have therefore only had access to flax fibres produced for textiles, or "textile waste", termed tow fibres. This picture is now changing in Europe as a number of new decortication / defibration techniques have been developed for production of "green" or "mechanical" flax and hemp fibres. The suitability for the use of such fibres in higher performance composite materials is presently being assessed in a number of research and industrial laboratories world-wide.

The present situation, therefore, is that a number of different processing routes are available for the

---

production of bast fibres. Each different approach produces fibres with subtly varied surface properties. In a composite material, the formation of a good interface between fibre and matrix polymer is crucial for performance. Hence fibre surface characteristics are of the utmost importance.

Issues related to the effects of processing of flax and hemp to produce fibres are dealt with in other presentations at this forum. This paper will therefore focus on the modification of surface properties to produce fibres with improved compatibility towards selected matrix materials currently used in composites. These modifications can be chemical, enzymatic or “physical”. The correct choice of modification will depend crucially on the method of fibre production and the intended end use. Issues to be addressed include:

- Presently developed methods for plant fibre modification (mainly hydrophobation) and their effectiveness
- Cost implications of an extra step during composite production.
- Potential for “on-line modification” during, for example, mat-forming.

Problems specific to both flax and hemp will also be addressed.

### **Tailoring product manufacturing processes to optimise the performance of plant fibres**

Dr Jamie Hague, Deputy Director, The BioComposites Centre, University of Wales, Bangor, UK

Bast fibres derived from plants such as flax, hemp and kenaf have potential applications as geotextile materials and as reinforcements for plastics and other composite materials, e.g., wood-based panels.

For geotextile applications it is evident that many of the traditional manufacturing processes for producing non-woven materials are adequate. As such, carding and cross lapping, and various air laying techniques are appropriate, the latter perhaps being most appropriate for processing the more brittle/short fibres, e.g., kenaf.

For the reinforcement of plastics, plant fibres are competing against synthetic/man-made fibres. There is an increasing body of evidence emerging from research conducted over the last decade that suggests that the success of plant fibres in these applications (or perhaps lack of it) is related to the incidence of damage induced in fibres during processing. It is evident that plant fibres such as flax and hemp are very susceptible to damage induced by mechanical processing; this can severely reduce the ability of these fibre types to impart good toughness properties to composites. This is less important where plant fibres are used as reinforcements in thermoplastics, since the plastics themselves are inherently tough. However, with thermoset resins, which are typically brittle, the issue of toughness is extremely important. Given this, processing and manufacturing strategies are required which either minimise the incidence of damage in fibres, or minimise the effects of fibre damage. As such, fibre processing methods which minimise mechanical energy inputs are likely to be the most appropriate, e.g., chemical pulping, steam explosion, ultrasonics for separating and isolating fibres; wet forming or air laying for forming reinforcing materials. In addition, the use of spun yarns/woven materials could reduce the detrimental effects of fibre damage.

The use of both woven and non-woven materials for reinforcing construction materials such as chipboard or OSB has also been investigated by some workers. Preliminary evidence suggests that improvements in strength and stiffness can probably be realised. However, the challenge remains to find cost effective approaches to facilitate manufacture of these materials.

### **EU-financed research on non-traditional industrial uses of biological fibres: Past projects and future plans**

Dr Johannes Klumpers, European Commission, DGXII.E.2, Life Sciences, Brussels, Belgium

The presentation reviews a) the reasons for Community funding in the renewable biomaterials sector, b) gives a rough overview on the use of renewables in industry, c) describes problems when using renewables and d) gives an overview on the last 10 years of community funding in the renewables sector.

a) The main reasons for funding are: establishment of new outlets for agricultural products, reduction of food surplus, to maintain or increase employment in rural areas, to reduce environmental impact and to increase competitiveness of European industry.

b) The world-wide production of biomass is approximately 170 milliard tons, whereof only 6 milliard tons are used, half of it as food. The use of renewables in industry has increased slightly for the past years. The

---

use of fibres for non-classical applications, e.g. for car parts increases, vegetable inks, lubricants and detergents based on green chemicals have a certain market success.

c) Market success of renewables is mainly hampered by big variations in quality, quantity and prices for the raw material. In addition, raw material production depends strongly on the financial aid schemes of the Common Agricultural Policy. Fossil fuels are available at historically low prices, which does not favour the market penetration of agricultural based materials. A solid, political framework, remaining constant for a longer period is needed to encourage industries to invest in green production.

d) The European Community funding for renewables including natural fibres started approximately 10 years ago. In the 4<sup>th</sup> Framework Programme, the so called chain approach was developed. Market orientation was recognised as a pre-requisite for success along the complete integrated production, processing, utilisation and disposal chain for green chemicals, polymers and fibres (wood and other natural fibres). A strong industrial participation and focus is thus essential. Around 25 projects, dealing with research on non-wooden natural fibres have been financed the last ten years. These projects received 36 million ECU contribution from the European Community.

Goals for the 5<sup>th</sup> Framework programme for Research, Demonstration and Technological Development are:

- to contribute to the establishment of a bio-based economy
- to contribute to the development of marketable products in several sectors by the year 2007
- to establish a new and durable relationship between farmers and the renewables industry.

## **TOPIC 4: THE FUTURE / NEXT STEPS**

**Topic Chairman:** Dr David Plackett, Visiting Professor, The Royal Veterinary and Agricultural University, Taastrup, Denmark

### **Green Cotton - an example of plant fibres in a sustainable development**

Mr Leif Nørgaard, Managing Director, Novotex A/S, Ikast, Denmark

The Green Cotton brand T-shirt will be presented as a case study of sustainable development from the textile industry that has relevance for other industries. The Green Cotton T-shirt was launched in 1986 as an environmental textile based on existing rules, laws and systems. It is a product that demonstrates the value of a common labelling system denoting “ecological commitment” to influence consumer purchasing decisions. A life cycle analysis of the product covers the processes involved in its production including transportation between the different places where the processes take place. The impact of EU regulations for the “green sector” are discussed under three headings: organic farming, eco-labelling and the eco-management and audit scheme. It is concluded that the EU regulations currently available for these three aspects with the addition of a commitment to ethics in the product production process will ensure product success with consumers now and in the future by providing a form of total manufacturing system.

### **Strategy for a sustainable future of fibre plants**

Rudolf Kessler, M. Tubach, and R. Kohler, Institut für Angewandte Forschung, Reutlingen, Germany

During the last decade, there have been great efforts in the EEC to establish flax and hemp as a sustainable source for fibres. Although almost every German car manufacturer uses now natural fibre reinforced parts, most of the raw material for the low level application comes still from Eastern Europe and Asia at cheap prices. Thus, the strategy to establish a sustainable use of plant fibres in high cost countries must be optimized.

The basic idea for a cost competitive future of flax and hemp is to provide tailor made high quality fibres for textile and non textile markets. A lot of work has been done to develop high performance composites on the laboratory scale. Very little progress can be noticed in marketing and high level processing. The paper will therefore outline the following topics:

- cooperative structures from raw material production to end users
- adaptive processing to balance variations in the raw material
- on line quality management for a feed back and a feed forward control

- 
- production of fine fibres by chemical and biochemical processing

Some typical examples will be given and high end use fibres will also be presented.

### **Perspectives on the utilisation of natural binders in composite materials**

Dr Claus Felby, Research Scientist, Novo Nordisk A/S, Bagsvaerd, Denmark

The term natural binders covers a wide range of adhesives. Natural binders can be in the form of a conventional type adhesive based on lignin, protein or hemicellulose which is added to the composite or it may be an enzyme capable of activating a fiber surface thereby enabling a fiber to fiber bonding. Much research has been made on such systems but so far none has reached a commercial level.

The presentation will give a quick introduction to adhesives and describe the current technical status of natural binder systems. Despite several attempts industrial implementation of natural binder systems has so far not been successful. The main reason for this is simply a poor performance of natural binders compared to the synthetic binders currently used by the industry. The presentation will address the problems associated with upscaling of natural binder systems to mill-scale conditions. Also a set of "minimum" performance parameters will be presented and discussed.

### **Scenarios on the futures of consumer attitudes and their use of sustainable products**

Mrs Ute von Reibnitz, Scenarios + Vision, Vence, France

Nowadays and even more tomorrow consumers live in a constantly changing world which overloads them every day with more information, ideas and influences as the average person can psychologically digest.

We can observe a variety of consumer attitudes and behavior styles; the diversity ranges from the technology minded to the smart and conscious consumer, looking for sustainable solutions.

Will the trend to sustainable products and services only be a flash light of a new age fashion or will it become the mainstream trend of the future?

How can we improve sustainable thinking and behaviour?

What are the driving factors which can change consumers attitudes?

All these questions have one common denominator: there is no clear and easy answer. In order to find the right answers we have to apply a planning tool, which helps us to explore the future consumer environments – Scenario-Techniques.

What are Scenario Techniques?

The hallmark of Scenario Techniques is to create alternatives in case of uncertainty and to assemble them into highly consistent scenarios. These scenarios are descriptions of possible future environments and are highly contrasting. Why do we have to take into account very opposite future situations? Because nobody knows the exact outcome of the future. If you are prepared for very different future situations you will be able to deal with any scenario between the two extreme archetypes.

Scenario Techniques help you to design strategies which take advantage of future opportunities and turn risks into opportunities. In order to deal efficiently with different challenges, risks and opportunities in the future, a master guideline which fits to both scenario extremes has to be developed.

Other features which are taken into account are wild cards such as technological breakthroughs in a specific area, an ecological disaster, a stock exchange crash or a sudden regional war. Scenario Techniques show you how wild cards will affect your company and how you can develop preventive measures which shield your company against the worst effects of these events.

How do Scenario Techniques work?

Scenario Techniques comprise the following eight steps:

#### *Step 1 – Task Analysis*

Analyze the subject's structure, the existing goals and strategies as well as strengths and weaknesses. Subject under study can be a company, a Strategic Business Unit (SBU), a product family, a product, a subject outside a company or you as a person including your career and life planning.

#### *Step 2 – External Influence Analysis*

---

Here we have to identify external areas and influence factors as well as their interrelationship and the system dynamics.

*Step 3 – Projections*

Anticipate the future development of the influence factors and create alternatives in case of uncertainties.

*Step 4 – Consistency Analysis*

Cluster all alternatives according to their consistency in order to form logical and plausible future scenario structures and select the most contrasting ones for the interpretation. A special software for the scenario calculation is available.

*Step 5 – Scenario Interpretation*

Describe the scenarios in an imaginative way, analyze their system dynamics and changes in the future.

*Step 6 – Consequence Analysis*

Identify future opportunities and risks in both scenarios and develop action items which maximize opportunities and turn risks into opportunities.

*Step 7 – Wild cards Analysis*

Analyze possible disruptive events (wild cards) and their effects on the subject under study in order to develop preventive measures reducing the worst effects of these events and to define reactive measures.

*Step 8 – Scenario Transfer*

Design a master guideline and a new, sustainable vision which can be successfully realized under both scenarios. The hallmark of such a master guideline is that it does not only integrate strategic aspects generated under both scenarios, but also innovative ideas coming from one scenario and made compatible with different futures !

Two highly contrasting scenarios describing the future consumer's environment e.g. developments in global economy, working structures and models, politics and legislation, technology (Information and Computer Technology), fiber technology) health and life styles, demographic structures, etc., will be outlined.

On the basis of these scenarios we identify future consumer attitudes and behavior and the driving forces which guide and change them. Then these aspects will be fused into a future-based master guideline which transforms consumers' behavior to the use of sustainable products.

Summary

Scenario Techniques are an indispensable tool for those who feel responsible not only for short-term success but also for sustainable prosperity. Scenario Techniques are recommended whenever the problem is complex, uncertain and has long-term effects. If all these characteristics apply to your problem, then you have to abandon the traditional forecasting methods and turn to Scenario Techniques.

In this sense, keep George Bernard Shaw's phrase in mind:

*“We are not made wise by the recollections of the past,  
but by our responsibility for the future.”*

## **SUMMARY AND CONCLUSIONS**

The speakers are Mr Melvyn Askew, Dr Roger Rowell and Mr Finn Rexen.



---

## ***Biographies of Chairpersons and Speakers***

### **Melvyn Askew**

Melvyn Askew was awarded a B.S. Hons (Agriculture) by the University of Newcastle Upon Tyne and M.Phil. by research by the University of Nottingham. He is currently Head of Alternative Crops and Biotechnology Group at CSL. This Group includes the industrial crops and all non-cereal food crops as well as crop biotechnology. The role involves research and development, liaison and maintenance of understanding of markets world-wide. He provides policy support to MAFF and other official departments in the UK and elsewhere.

Melvyn Askew's previous employment was with ADAS as Head of Arable Crop Development; prior to that he was with the National Specialist in Non-Cereal Cash Crops from 1984 to 1992; Arable Crops Agronomist in the West Midlands; Agricultural Advisory Officer in South Notts and, earlier, Agricultural Advisory Officer in Northants.

Melvyn Askew is a member of international societies on rapeseed, sugar beet and potatoes and the co-ordinator of the IENICA project recently funded by the European Commission. IENICA (Interactive European Network for Industrial Crops and their Applications) runs for 3 years and involves 14 EU states.

He has travelled widely, more recent visits including Canada and USA to examine the introduction of transgenic crops, Belarus to lecture and discuss projects on oilseed rape and industrial crops and Italy to discuss Crambe, a new oilseed.

### **Jorn Behage**

Jorn Behage is the Managing Director of Proterra in Wageningen, The Netherlands. He has worked as an environmental consultant in Germany and the Netherlands and was in 1995 the founder of Proterra, an international centre which promotes the application of renewable resources in durable goods, packaging and disposables. Currently he is responsible for market development projects in the Netherlands and works primarily on biocomposites for the building industry. He is author of several articles about the market potential and application possibilities of biodegradable polymers and co-author of the book "Ten minste houdbaar tot..." based on the Dutch demonstration project: "Packing with biodegradable polymers". For this project and publication Proterra received the Monsanto Pledge Awards '98.

### **Jan E. G. van Dam**

Jan E.G. van Dam was born on 10 June 1953 in Schoonhoven, The Netherlands. After studies in organic chemistry of natural products and pharmacognosy at the State University of Utrecht, a PhD thesis was elaborated at the department Bio-Organic Chemistry on carbohydrate chemistry and (bio)chemical modification of bacterial polysaccharides. Since 1990 employed as programme leader at the Agrotechnological Research Institute (ATO-DLO) in Wageningen, The Netherlands, in the department Agrofibrres and Cellulose.

Extensive research programmes on new applications for agrofibrres (flax and hemp) have been carried out on behalf of the Dutch Ministry of Agriculture, Fisheries and Nature Management. Besides pulp and paper technologies, major activities are oriented on process and product development for plant fibre reinforced composites (thermoplastics as well as thermosets), building and construction materials (mineral fibre replacement, insulation, cement- and fibre boards), geotextiles, packaging, paper and pulp, non-wovens, and other innovative applications.

Major tasks within the department of Agrofibrres and Cellulose of ATO-DLO are scientific coordination, new business and industrial consultancy and international networking. Fundamental and applied industrial research is being carried out to develop novel industrial applications for fibre crops (flax, hemp, jute, kenaf, coir) in a variety of end-markets. Investigations are carried out on fibre morphology and chemical composition in relation to fibre quality, fibre extraction and modification processes to improve product properties for specific applications.

---

## **Claus Felby**

Claus Felby is currently a Research Scientist with Novo Nordisk A/S in Bagsværd, Denmark. He has a PhD in wood chemistry from The Royal Veterinary and Agricultural University. His previous work includes research on wood/plastic composites and wood adhesives, biotechnology applications for wood-based boards and panels, basic work on oxidative enzymes used on lignin, electron transfer in aromatic polymers, biotechnology applications within pulp and paper and starch degrading enzymes.

## **Axel Herrmann**

Dr.-Ing. Axel Siegfried Herrmann was born on 13 March 1958 in Hamburg-Altona. He attended the Technical University in Clausthal, Germany, from 1979 until 1985 where he undertook studies in mechanical engineering (speciality in machinery engineering) and received a Dipl.-Ing. (diploma'd engineer). From 1985 to 1989 he studied at the Technical University in Clausthal, Germany, taking the doctor's degree of engineering science in the field of mechanics and during this time was also a Scientist at TU Clausthal Institute of Technical Mechanics. In 1989 he was academic councillor at TU Clausthal, responsible for staff and results of industrial research cooperation. From 1987 until 1989 he held a lectureship at 'Berg- und Hütterschule' (mining technical school) in Clausthal. He was Head of the Demonstration Centre of Fibre Reinforced Composites and Deputy Head of the Department Composite Structures at 'Deutsche Forschungs- und Versuchsanstalt für Luft- und Raumfahrt e. V.' (German Aerospace Research Establishment) from 1989 until 1993 and since then has been Head of the Department Composite Technology and Demonstration Centre at 'Deutsche Versuchsanstalt für Luft- und Raumfahrt e. V.', responsible for the department's activities in the field of aerospace and technology transfer. From 1995 to present he has been Head of the technical committee 'Materials' at DGLR (German Aerospace Association). Since 1994 he has held a lectureship at TU Clausthal (topic: 'Mechanics of Fibre Reinforced Composites') and since 1996 he has been a general partner and consulting engineer at INVENT GmbH.

## **Rudolf Kessler**

Rudolf Kessler, born in 1949, is a Professor of Chemistry at Fachhochschule (University of Applied Science) and the Director of the Institut für Angewandte Forschung (Institute for Applied Research).

After his apprenticeship and military service in 1970 he studied Polymer Chemistry at the State Engineering School at Reutlingen. He finished his degree as Dipl.Ing. (FH) in 1973 and continued his studies in Chemistry at the University of Tübingen, Germany. In 1977 he graduated as a Chemist (Diploma) with a thesis on fluorescent spectroscopy and laser flash photolysis. During his PhD he spent a year in Britain.

From 1981 until 1985 he worked with Daimler Benz research department at Stuttgart. His main research areas were on alternative energy and materials science of metals and catalysts. In 1985 he joined the Fachhochschule Reutlingen, Department of Applied Chemistry.

His main research areas are in process analysis by optical and spectroscopic methods in combination with multivariate data analysis and neural networks. He also conducts research on natural fibre qualification and processing such as steam explosion.

In 1991 he founded the Institut für Angewandte Forschung and is since then its director and head of the working group Process Analysis. He has had several research stays abroad, e.g., USA, China, etc. He is a member of the German and American Chemical Societies and was responsible for several international committees on biobased materials. He is a member of the editorial board for two International Journals on biobased materials and has published around 80 scientific papers and owns several patents.

## **Johannes Klumpers**

Johannes Klumpers was born on 11 April 1964 in Geneva, Switzerland, and has German nationality. He has a university degree in Forest Sciences (Diplom-Forstwirt), University of Munich, Germany; a university degree in Wood Sciences (DEA "Sciences du Bois"), Nancy, France; and a doctoral degree in Wood Sciences, ENGREF, Nancy, France. He has been Researcher at INRA in Nancy, France, and Project Manager at Södra Timber AB in Växjö, Sweden. Since May 1998 he has worked at the European Commission, Directorate General XII "Research", in Brussels, Belgium.

---

## **Ryszard Kozlowski**

Prof. Dr. Ryszard Kozlowski has worked at the Institute of Natural Fibres in Poznan since 1961. From 1976 up to now he has been the Director of the Institute of Natural Fibres. Leading the activity of the Institute, Prof. Kozlowski initiated and conducted research on broadening the raw material resources of natural fibres (flax, hemp, wool and silk), extracting and processing of bast fibres, environmental protection, fire protection and utilization of by-products and composites from bast fibrous plants. He is a specialist in the field of natural and man-made fibers, raw materials and also lignocellulosic bio-composites.

Professor Kozlowski works for many international organizations: he acts as Coordinator of the FAO European Cooperative Research Network on Flax and Other Bast Plants within the FAO ESCORENA system; Member of the Council of International Textile Institute, Manchester, UK; Vice Chair of the Poland TI Section and Poland National Committee; Member of International Council on Monuments and Sites; Member of SSARM - Society for Sustainable Agriculture and Resource Management, India; Member of FIBA, FABI.

As a visiting professor he gave many lectures at universities and research centres all over the world, e.g., Canada, China, Finland, Japan, UK, USA and others. He is the author and co-author of more than 150 original papers, 5 books (two of them as co-author), 21 patents, 24 implemented technologies. Editor-in-Chief of: Natural Fibres; "EUROFLAX" Information Bulletin of the FAO Network; "COLOURAGE", India - Honorary Poland Consulting Editor.

## **Mark Lawther**

Mark Lawther was born in 1958 and comes from the North of England, but presently lives and works in Denmark. He received a BSc in Applied Chemistry, University of Northumbria, Newcastle upon Tyne, UK, in 1983. In 1986 he received his PhD from the University of Newcastle, UK, where he studied interactions of an electron transfer protein with lipid surfaces focusing on the kinetics of electron transfer between a solution phase and a surface. Between 1986 and 1989 he was a Post-Doctoral Research Fellow in the Department of Forestry and Wood Science, University of Wales, Bangor, UK, where he worked in Professor Bart Banks' group on the modification of cellulose and derivatives for industrial end uses. He then joined the

BioComposites Centre, University of Wales, Bangor, UK, first as Research Manager (1990 - 1994) and then as Deputy Director (1994 - 1996), where he was involved with research and management of a growing number of UK, EU and industrially funded projects based on natural polymers, wood/plant fibres and composites. In December 1996 he was appointed professor of Plant Fibre Technology at The Royal Veterinary and Agricultural University, Copenhagen, Denmark where he is working on the characterisation and increased utilisation of plant fibres and polymers in composites with a focus on fundamental properties. Professor Lawther is the author or co-author of around 35 refereed papers, 10 conference papers, 5 book chapters and a number of conference posters.

## **Flemming Duus Mathiesen**

Flemming Duus Mathiesen has been working all his career in the Danish Ministry of Agriculture, later the Ministry of Agriculture and Fisheries, and now the new Danish Ministry of Food, Agriculture and Fisheries, Danish Directorate for Development.

Since 1996 Flemming Duus Mathiesen, has been director for research and development, responsible for the administrative and strategic coordination of research and development within the new Ministry of Food, Agriculture and Fisheries in Denmark.

Flemming Duus Mathiesen has been involved in several internal and external committees working with topics related to research and development in the food sector both in relation to the domestic market and the international market conditions, formulation of strategies for agro-environmental relations, consumer aspects, innovation and industrial development.

Flemming Duus Mathiesen is also as Danish representative member of the EU Commission's SCAR Committee, and member of the new Programme Committee for the 5th Framework Programme, Quality of Life and Management of Living Resources.

Flemming Duus Mathiesen is educated from the Royal Veterinary and Agricultural University in Copenhagen

---

in 1973.

### **Laurence Mott**

Laurence Mott has published over 20 papers in the field of natural fibre research. He has a keen interest in understanding the contribution of fibre cell wall defects to bio-composite performance. Laurence obtained post-graduate degrees from the University of Wales, UK, and from the University of Maine, USA. While working as a post-doc in the USA, as a Research Manager at The BioComposites Centre UK, and in his present position at Perstorp AB in Sweden, he has maintained his interest in developing composites through the improved utilisation of natural fibres.

### **Gary Newman**

After five years as a construction engineer, Gary Newman changed direction and studied for an M.Sc. in Forest Industries Technology at Bangor University. In 1992 he joined the BioComposites Centre, where he worked as a research scientist on a number of contract research projects, broadly concerned with the technology relating to the utilisation of wood and plant fibres. In 1996 Gary left the BioComposites Centre to head a spin-off manufacturing venture, JB Plant Fibres. This company develops and manufactures novel plant fibre nonwovens for composite and biodegradable applications, specialising in the utilisation of the new European-grown hemp and flax fibres.

### **Leif Nørgaard**

Leif Nørgaard has been the Managing Director of Novotex since he founded the organisation in 1983. For the previous seven years he was Sales Director of Icast of. Prior to that time he spent two years in Tanzania as a Lecturer in economics and one year as an external lecturer on East-West trade for the Århus School of Business while he completed his compulsory service in the army. In 1973 he completed an M. Com. degree at the Århus Business School. In 1987 he received environmental awards in both Denmark and Europe. He was awarded a North American Design and Environment Award in 1994 and a European Better Environment Award in the same year. Leif Nørgaard currently serves as Chairman of the Textile Panel of the Danish Environmental Protection Agency and is a board member of the Federation of Textile Manufacturers and of the International Natural Textile Association. In addition, he was chairman of Green City Denmark (1993-1998) and a board member of Greenpeace in Germany and of the British Telecom Environmental Panel.

### **Per Ole Olesen**

Per Ole Olesen is currently Professor, Plant Fibre Technology at The Royal Veterinary and Agricultural University (KVL) and the Executive Chairman and Head of the Centre for Plant Fibre Technology. The Centre is a collaborative partnership of five organisations - two universities, two research institutes and a major Danish company - that brings together a wide range of expertise and facilities to undertake research and development on environmentally friendly processes and products using plant fibres. He was previously Professor, Forest Technology, within the Forestry Institute at KVL from 1994-1997 and Curator of The Hunting and Forestry Museum for Denmark from 1978-1984. Prior to this time he spent two years at the University of Dar es Salaam, Tanzania, as a Senior Lecturer (wood technology, silviculture, and wildlife ecology) and three years as Senior Research Fellow, Wood Technology, at KVL.

Between 1969 and 1972 he undertook his PhD studies focused on tree breeding at KVL followed by a year as a Research Worker at the Danish Technological Institute (impregnation and biological deterioration). He spent the years 1967 to 1969 with the Malawi Forest Research Institute as a tree breeding specialist and 1963 to 1967 at various state forests in Denmark as assistant forest officer or acting chief officer. He commenced his career as a Research Officer with KVL in silviculture following the completion of his Master of Forestry degree there in 1962.

Per Olesen was awarded a doctoral degree in 1983 for his research on the maturation processes of the apical meristem and its importance for the developmental changes of the lateral meristem.

He was honoured for research contributions to Denmark with the Dana Glue Prize in 1997. He holds

---

memberships in Denmark's Academy of Technical Sciences and the Society of Wood Science and Technology. He is currently Chairman of the National Wildlife Management Council and of the Non-Food Committee of KVL and is a member of the board of the following organisations: the Danish Furniture Foundation, the BioRaf Foundation, the Loevenholm Foundation, the National Programme for Forestry and Wood Industry and the O.H.F. and A. J-E. Heilmanns Foundation.

### **David Plackett**

David Plackett is currently Visiting Professor, Wood Chemistry, at the Centre for Plant Fibre Technology at Denmark's Royal Veterinary and Agricultural University, where he is undertaking research on the chemical modification of plant fibres and the performance properties of plant fibre-reinforced polymers. He has previously worked as Research Manager, Composites and Treated Wood Products, at the Vancouver laboratory of Forintek Canada Corporation, Canada's national wood products research institute and before that as Group Leader, Product Development, with the New Zealand Forest Research Institute. While in New Zealand Dr Plackett was the recipient of the first New Zealand Forest Products Jubilee Fellowship (1987) and in 1992 he chaired the first of the Pacific Rim Biocomposites Symposia. His experience also includes five years with the research arm of MacMillan Bloedel, one of Canada's largest forest products companies. Dr Plackett obtained his BSc from the University of Sussex and his PhD in chemistry from the University of British Columbia.

David Plackett has over 50 publications and one patent and, since 1995, has been Coordinator for Group S5.05 (Composites and Reconstituted Wood Products) within IUFRO (International Union of Forestry Research Organisations). He is also presently a member of the Expert Group on Renewable Materials with the United Nations Environment Program Working Group on Sustainable Product Development.

### **Ute Helene von Reibnitz**

Ute Helene von Reibnitz was born in 1951 in Trier, Germany. She got her education in marketing, innovation and planning techniques at the Technische Hochschule Darmstadt. She worked at Unisys, Horten and Battelle-Institute, Frankfurt. In 1982 she became a freelance consultant in Germany. In 1993 she relocated to France and founded her consulting company Scenarios + Vision. Ute Helene von Reibnitz works in three languages (English, French and German) and gives lectures at various universities. She applies prospective and problem-solving methods (scenario techniques, strategic planning, simulation, systematic techniques) in various approaches tailored to clients' needs. Her clients comprise multinational to medium-sized companies in Europe, Middle East, USA, from the sectors aerospace, automotive, biotechnology, chemistry, consumer goods, financial services health care, information and communication technology, pharmaceuticals, retail, and transportation.

### **Finn Rexen**

Finn Rexen is educated as chemical engineer and has a Master of Business Administration. He was head of section/division at the Biotechnical Institute, Kolding (1964-79) followed by Kockums Construction, Sweden, Head of Division (1979-80), Carlsberg Research Centre, Copenhagen, Dept. of biotechnology (1980-88), EU Commission, DG XII, Bruxelles, Head of Division (1988-94), and Ministry of Food, Agriculture and Fisheries, Directorate for Development, Head of Non-food Secretariat. (1994-).

### **Roger Rowell**

Roger Rowell has been a Research Chemist and Project Leader with the USDA Forest Products Lab in Madison, Wisconsin, since 1966. In 1980 he was appointed Professor in the Department of Forestry and from 1983 he has been Research Professor, Department of Technical Chemistry and Forest Products at Chalmers University of Technology in Göteborg, Sweden. Since 1995 he has been Professor, Biological Systems Engineering Department of the University of Wisconsin and from 1996 has been professor at the Engineering Research Centre for Plasma Aided Manufacturing at the University of Wisconsin. For part of 1985 he was a Guest Professor in the Forest Chemistry Department, Beijing Forestry University in Beijing, China, and for part of 1986 a National Science Foundation Exchange Professor at the Wood Research Institute, Kyoto University, in Uji, Japan. For part of 1986 he was a Guest Professor, Department of Wood Science, University College of

---

North Wales in Bangor, UK, and for part of 1988 he was a Guest Research Fellow at the Forest Research Institute, Rotorua, New Zealand. For part of 1991 he was a Guest Fellow at Kyoto University, Kyoto, Japan. For part of 1993-1998 he was United Nations Development Project Mission Leader for composites in India. He was elected Fellow of the International Academy of Wood Science and American Chemical Society - Division of Cellulose, Paper and Textiles. In 1995 he received the United States Department of Agriculture Group Honor Award for Excellence in Research; in 1996 he was awarded its Federal Laboratory Consortium Award of Merit for Technology Transfer and in 1998 its Honor Award for Personal and Professional Excellence in Research and the Forest Service Chief's Award. He has over 250 publications, has edited 9 books and holds 22 patents.

### **Bent Schmidt-Nielsen**

Bent Schmidt-Nielsen is Vice Chancellor for the Royal Veterinary and Agricultural University a position he has had since 1987.

### **Thomas Schuh**

Thomas Schuh studied Material Science and Engineering at the University of Saarland in Saarbrücken, Germany. After fundamental research in the field of nano-crystalline materials he wrote his Ph.D. thesis on grain boundary segregation effects.

In 1986, he joined the Daimler-Benz corporation. Since 1993 his activities have focused on fundamental development in polymers with an emphasis on the application of renewable materials.

Today, as head of the department "Plastics, Elastomers, and Natural Materials" in the Materials Engineering Department, he is responsible for the application of polymeric materials in Mercedes cars.

### **Lars Thøgersen**

Lars Thøgersen is 38 years of age and has been working with industrial design for about 15 years. He has designed, developed and produced children's furniture since the beginning of the 1980s.

He has always been very interested in environmental issues. When developing new products he finds it essential that environmental issues are given priority because they are a major factor in the successful construction and production of the new products.

For the last almost 10 years he has been particularly involved in the development of a number of products used in different services in the commercial aircraft industry. Some of the assignments have to do with waste handling onboard the aircraft. In this project he has been working with a number of different possibilities: modified PE and PP, starch-based materials and natural fiber applications.

Today he is the owner of CPH Industrial Design - a company that is working with development of a large variety of products, mostly business-to-business products from concept studies through design and construction to serial production. His company has a team of seven industrial designers and engineers.

## List of Participants

Participant	Company	Country
<b>ADAMSEN ANDERS PETER</b> MR.	APSA MILJOE	DENMARK
<b>AKKERMAN JACOB</b> HR.	FORBO-KROMMENIE	NETHERLANDS
<b>AMADUCCI STEFANO</b> DR.	DEPARTMENT OF AGRONOMY WAV	NETHERLANDS
<b>ANDER PAUL</b> ASSOC. PROF	SWEDISH UNIV. AGRIC. SCIENCES	SWEDEN
<b>ANDERSEN TOM LØGSTRUP</b> MR.	RISØ NATIONAL LABORATORY	DENMARK
<b>ARTAL GERARDO CORREAS</b> PRODUCT DEVELOP. MANEGER	CELULOSA DE LEVANTE S.A	SPAIN
<b>ASAREN KWABENA GODWIN KWABENA</b> MR.	GHANA CO-OPS COUNCIL	GHANA
<b>ASKEW MELUYN</b> MR.	CENTRAL SCIENCE LABORATORY	UNITED KINGDOM
<b>BAADSGAARD-JENSEN JØRGEN</b> HEAD OF SECTION	DANISH TECHNOLOGICAL INSTITUTE	DENMARK
<b>BACH LARS</b> ADD. PROF & PROJECT MANEGER	UNIVERSITY OF ALBERTA	CANADA
<b>BAETENS EDDY</b> DR.	CENTEXBEL	BELGIUM
<b>BATESON ROBERT</b> MR.	FLAX UK LTD	UNITED KINGDOM
<b>BAZELEY NIGEL</b> MR	BRITISH FIBRE	UNITED KINGDOM
<b>BEHAGE JORN EKKEHART</b> MR	PROTERRA	THE
NETHERLANDS		
<b>BERGENDORFF MADS</b> GRADUATE ENGINEER	DSB ENVIRONMENTAL OFFICE	DENMARK
<b>BERTELSEN HARRY HEINRICH GÜLLICH</b> MR	AURORA DEVELOPMENT / EOS-INNOVATION	DENMARK
<b>BEWA HILAIRE</b> DR.	ADEME	FRANCE
<b>BIGARRE PASCAL</b> MR.	SORGHAL	BELGIUM
<b>BJØRKMAN ANDERS</b> PROF.	DTU	DENMARK
<b>BLICHER-MATHIESEN ULLA</b> SCIENTIFIC ADVISER	DANISH DIRECTORATE FOR DEVELOPMENT	DENMARK
<b>BLIENINGER FRANZ</b> DIPLOM KAUFMANN	BLIENINGER HOLZSPÄNE GYMBH	GERMANY
<b>BOUTRUP JOY</b> TEXTILE ENGINEER	DANMARKS DESIGNSKOLE	DENMARK
<b>BOWEN-NIELSEN JAN</b> BUSINESS DEVELOPMENT MANEGER	GRODANIA A/S	DENMARK
<b>BRODSJO ANDERS</b> CONSTRUCTION ENGINEERS	CENTRE OF LIGHT-WEIGHT STRUCTURES	NETHERLANDS
<b>CHANDLER BRIAN</b> MR	ADTECH LIMITED	UNITED KINGDOM
<b>CHRISTENSEN LASSE</b> MR.	RISØ NATIONAL LABORATORY	DENMARK
<b>CHRISTENSEN LENA HOLM</b> ARKITEKT MAA	BIOSYSTEMER	DENMARK
<b>DAHL INGER MARIE</b> SUNDHEDSPLEJERSKE	STUBBEKØBING KOMMUNE	DENMARK
<b>DE VRIES SIP S.</b> MR.	OBL	NETHERLANDS
<b>DREYER JENS</b> DR.	UNIVERSITY OF HAMBURG	GERMANY
<b>DUPIC CHRISTOPHE</b> MR.	EPILOIR	FRANCE
<b>EINARSSON SIGURBJÖRN</b> MR	TECHNICAL INSTITUTE OF ICEALND	ICELAND
<b>ELMETOFTE CHRISTINA</b> HEAD OF SECRETARIAT	THE ROYAL VETERINARY AND AGRICULTURAL UNI.	DENMARK
<b>ERNEGG MARTIN</b> MR	ZELLFORM GMBH	AUSTRIA
<b>FALLESEN BJARNE</b> ENVIRONMENTAL MANAGER	DANISCO SUGAR	DENMARK
<b>FISCHER GINA</b> FORSKNINGSASSISTENT	THE ROYAL VETERINARY AND AGRICULTURAL UNI.	DENMARK
<b>FLENGMARK POUL</b> SCIENTIST M. SC.	DANISH INSTITUTE OF AGRICULTURAL SCIENCE	DENMARK
<b>FODGAARD SØREN</b> MR.	DANISH FORESTRY ASSOCIATION	DENMARK
<b>FOLTING PETER</b> FORSKNINGSASSISTENT	THE ROYAL VETERINARY AND AGRICULTURAL UNI.	DENMARK
<b>FORSMAN JAN</b> DR.	PERSTORP AB	SWEDEN
<b>FREDERIKSEN HENNING</b> MR.	RISØ NATIONAL LABORATORY	DENMARK
<b>FRYDENDAL IB</b> CIVIL INGENIØR, PHD	LM GLASFIBER A/S	DENMARK
<b>GILBERTSON H.</b>	BRITISH FIBRE	UNITED KINGDOM
<b>GOUDE MARIO</b> MR	LULEÅ TEKNISKA UNIVERSITET	SWEDEN
<b>GRIMM ECKHARD</b> DR	MARTIN-LUTHER-UNIVERSITÄT	GERMANY
<b>GYDESEN JENS FOLMER</b> MR	PRESSALIT A/S	DENMARK
<b>GYLLING MORTEN</b> FORSKNINGSKONSULENT	STATENS JORDBRUGS- OG FISKERI -	DENMARK
<b>GØTZSCHE-LARSEN KAREN</b> MRS	DANISH TECHNOLOGICAL INSTITUTE, CENTRE F	DENMARK
<b>HAROLD MALCOLM</b> MR	WARWICK MANUFACTURING GROUP	UNITED KINGDOM
<b>HASSINGBOE JAKOB</b> STUD. PH.D	THE ROYAL VETERINARY AND AGRICULTURAL UNI.	DENMARK
<b>HASSINGBOE JENS</b> STUD. PH.D	THE ROYAL VETERINARY AND AGRICULTURAL UNI.	DENMARK
<b>HENRIKSEN JENS-ULRIK</b> MR.	VELUX A/S	DENMARK
<b>HERBINGER BIRGIT</b> MISS	INSTITUTE FOR AGROBIOTECHNOLOGY	AUSTRIA
<b>HERRMANN BIRGIT</b> MRS.	FACHAGENTUR NACHWACHSENDE ROHSTOFFE E.V.	GERMANY
<b>HOBSON JOHN</b> MR.	HEMCORE LTD	UNITED KINGDOM
<b>HUGO SARAH</b> MISS	CENTRAL SCIENCE LABORATORY	UNITED KINGDOM
<b>HULST A.C</b> DR.	AVEBE	NETHERLANDS
<b>IVERSEN METTE</b> MRS	KASTRUPGAARD	DENMARK
<b>JENSEN GEORG</b> FORSTFULDMÆGTIG	SKOV- OG NATURSTYRELSEN	DENMARK
<b>JENSEN TORBEN HOVE</b> MANAGING DIRECTOR	UDVIKLINGSLABORATORIET APS	DENMARK
<b>JONSSON TOMMY</b> MD	EKVITEC AB	SWEDEN
<b>KERRN-JESPERSEN TOBIAS</b> FULDMÆGTIG	MINISTRY OF FOOD, AGRICULTURE AND FISHERIES	DENMARK
<b>KLUMPERS JOHANNES</b> DR.	EUROPEAN COMMISSION	BELGIUM
<b>KOZLOWSKI RYSZARD</b> PROF. DR	THE INSTITUTE OF NATURAL FIBRES	POLAND
<b>KUIVALAINEN YRJÖ</b> MANEGER R&D	KOTINI EUROPA OY	FINLAND
<b>LARSEN ERIK</b> PROF	KEMISK INSTITUT, KVL	DENMARK
<b>LAWTHER MARK</b> PROFESSOR	THE ROYAL VETERINARY AND AGRICULTURAL UNI.	DENMARK
<b>LENAU TORBEN</b> DR	DEP. OF MANUFACTURING ENGINEERING	DENMARK

LILHOLT HANS <i>MR.</i>	RISØ NATIONAL LABORATORY	DENMARK
LOPES TERESA	EUROPOINT BV	NETHERLANDS
LUND JENSEN SØREN <i>DR.</i>	ROCKWOOL INTERNATIONAL A/S	DENMARK
Participant	<b>Company</b>	<b>Country</b>
MACKINTOSH RENALD D- <i>MR.</i>	PERNOVO AB	NETHERLANDS
MADSEN MARIANNE H. <i>DR.</i>	DANISH INSTITUTE OF AGRICULTURAL SCIENCE	DENMARK
MATHIESEN FLEMMING DUUS <i>DIRECTOR GENERAL</i>	DANISH DIRECTORATE FOR DEVELOPMENT	DENMARK
MCNAUGHTON D.	ROBIN APPEL LTD	UNITED KINGDOM
MIKKELSEN CLAUS <i>MR.</i>	RISØ NATIONAL LABORATORY	DENMARK
MOTT LAURENCE <i>DR.</i>	PERSTORP AB	SWEDEN
MUNDIGLER NORBERT <i>DR.</i>	INSTITUTE FOR AGROBIOTECHNOLOGY	AUSTRIA
MURRAY JOHN <i>DR.</i>	ADTECH LIMITED	UNITED KINGDOM
MÖLLER FRANK	FAL INSTITUT FÜR BAUFORSCHUNG	GERMANY
NEEL MICHEL <i>DR.</i>	ISOROY	FRANCE
NEWMAN GARY <i>MR.</i>	JB PLANT FIBERS	UNITED KINGDOM
NIELSEN BRUNO SANDER <i>M. SC., ADVISOR</i>	LANDBRUGSRAADET	DENMARK
NIELSEN JOANNA MØLLER <i>LABORANT</i>	THE ROYAL VETERINARY AND AGRICULTURAL UNI.	DENMARK
NIELSEN LARS-BO <i>CIV.ING</i>	FORCE INSTITUTTET	DENMARK
NOER TORBEN <i>MR.</i>	EXIL DESIGN	DENMARK
NORHOLT HENRIK <i>MR.</i>	IDA A/S	DENMARK
OLESEN ANNE BJERRING <i>FORSKNINGSASSISTENT</i>	THE ROYAL VETERINARY AND AGRICULTURAL UNI.	DENMARK
OLESEN PER OLE <i>CENTRALLEDER OG PROFESSOR</i>	THE ROYAL VETERINARY AND AGRICULTURAL UNI.	DENMARK
OLIVEROS RAFAEL <i>DR.</i>	KENINTER S.L.	SPAIN
OLSEN OLE <i>MR.</i>	RISØ NATIONAL LABORATORY	DENMARK
PALLESEN BODIL ENGBERG <i>RESEARCHER</i>	DANISH AGRICULTURE AND ADVISORY CENTRE	DENMARK
PEGON LAURENCE <i>MRS</i>	PRABIL	CANADA
PETERSEN ERLAND <i>MR.</i>	SENNERSKOV PRESSER A/S	DENMARK
PLACKETT DAVID <i>PROFESSOR</i>	THE ROYAL VETERINARY AND AGRICULTURAL UNI.	DENMARK
PLACKETT PATRICIA <i>FAGLIG SEKRETÆR</i>	THE ROYAL VETERINARY AND AGRICULTURAL UNI.	DENMARK
PROBERT ANDREW <i>MR.</i>	ROBIN APPEL LTD	UNITED KINGDOM
RASMUSSEN KNUD <i>MR.</i>	FORCE INSTITUTTET	DENMARK
REXEN FINN <i>HEAD OF DEVISION</i>	DANISH DIRECTORATE FOR DEVELOPMENT	DENMARK
SCHADE JAN ROBERT <i>MR.</i>	CONSULTANT IN MECHANICAL AND	DENMARK
SCHMIDT ANETTE S. <i>RESEARCH SCIENTIST</i>	RISØ NATIONAL LABORATORY	DENMARK
SCHWARZ KAI-UWE <i>DR.</i>	DANISH INSTITUTE OF AGRICULTURAL SCIENCE	DENMARK
SIMONSON RUNE <i>PROF.</i>	CHALMERS UNIV. OF TECHNOLOGY	SWEDEN
SKOVGAARD IB <i>HR.</i>	DE DANSKE LANDBOFORENINGER	DENMARK
SKOVGAARD MARIANNE <i>MRS</i>	THE DANISH PLASTICS FEDERATION	DENMARK
SMEDER BO <i>STUD. PH. D</i>	THE ROYAL VETERINARY AND AGRICULTURAL UNI.	DENMARK
SOMMER ELLIS BYRGIEL <i>CIVILINGENIØR</i>	DANISH DIRECTORATE FOR DEVELOPMENT	DENMARK
SOMOGYI ZOLTA'N <i>DR.</i>	OMFB	HUNGARY
SPEEDING C. <i>MR.</i>	ROBIN APPEL LTD	UNITED KINGD
STEWART DEREK <i>DR.</i>	SCOTTISH CROP RESEARCH INSTITUTE	SCOTLAND
SVENNERSTEDT BENGT <i>ASSOC. PROF</i>	SWEDISH UNIVERSITY OF AGRICULTURAL SCIEN	SWEDEN
SVENSSON MARTIN <i>DR.</i>	SVENSKA LANTMÄNNEN, R&D	SWEDEN
TED WILLIAMS <i>DR.</i>	BRITISH SUGAR TECHNICAL CENTRE	UK
THEOBALD TREVOR <i>DR.</i>	BRITISH SUGAR TECHNICAL CENTRE	UK
THOMSEN ANNE BELINDA <i>MRS</i>	RISØ NATIONAL LABORATROY, PLANT BIOLOGY A	DENMARK
THOMSEN NIELS BJERRUM <i>DR.</i>	VELUX A/S	DENMARK
TOFTEGAARD HELMUTH <i>MR.</i>	RISØ NATIONAL LABORATORY	DENMARK
TOONEN MARCEL <i>DR.</i>	CPRO- DLO	NETHERLANDS
TORGILSSON RONNY <i>FORSKNINGSASSISTENT</i>	THE ROYAL VETERINARY AND AGRICULTURAL UNI.	DENMARK
TUCKER NICK <i>DR.</i>	WARWICK MANUFACTURING GROUP	UNITED KINGDOM
VAN DAM JAN E.G. <i>DR.</i>	ATO-DLO	NETHERLANDS
VAN DER LAAN RUBEN <i>CONSTRUCTION ENGINEERS</i>	CENTRE OF LIGHT-WEIGHT STRUCTURES	NETHERLANDS
VUORIO JOHANNA <i>STUDENT</i>	HELSINKI UNIVERSITY OF TECHNOLOGY	FINLAND
WEBER CLAUS <i>DR.</i>	KVL, DEPARTMENT OF DAIRY & FOOD SCIENCE	DENMARK
WEIDNER MORTEN <i>DR.</i>	IDA A/S	DENMARK
WESTERMARK ULLA <i>PROF.</i>	LTU	SWEDEN
WESTIN MATS <i>DR.</i>	CHALMERS UNIVERSITY OF TECHNOLOGY	SWEDEN



---

## Poster Abstracts

### P1. Coupling of phenols to lignin in pulp fibres and potential use of the fibre product

Paul Ander<sup>1</sup>, Karin Grabner<sup>2</sup>, and Kurt Messner<sup>2</sup>

Labelled synthetic lignin (<sup>14</sup>C-ring-labelled DHP), different phenols like vanillic and ferulic acids as well as tritium-labelled tyrosine were coupled to lignin in different kraft and sulfite pulps using potassium ferricyanide at pH 10. As a comparison the oxidative enzyme horseradish peroxidase plus hydrogen peroxide at pH 6.5 was also used as oxidant. The technique is based on the simultaneous formation of phenoxy radicals from both the lignin in unbleached pulp and the labelled DHP or the phenols. These radicals couple and form covalent bonds resulting in a labelled pulp. With K-ferricyanide as oxidant at pH 10, the label penetrated deeper into the fibre giving high specific activity and little variation in released label after enzyme treatment.

The chemically labelled pulp (CLKP) was used in a small scale (30 mg pulp in 1.5 ml buffer) for testing ligninolytic enzymes and mediators for possible use in pulp bleaching. The results from this assay correlated well with laccase/mediator kraft pulp delignification plus TCF-bleaching. Coupling to cellulose was shown to be one fifth of the coupling to lignin.

The potassium ferricyanide method is a general method for coupling of both labelled and unlabelled lignins, phenols and aromatic amines to the lignin in kraft and sulfite pulps, thermomechanical pulps and also to fibreboard and wood fibres giving new interesting fibre products. Release of either <sup>14</sup>C- or <sup>3</sup>H-label can easily be followed during chemical, enzymatic and other treatments. In addition, it is possible that location of lignin in kraft pulp can be studied after labelling with tritium and visualisation in microautoradiography and transmission electron microscopy.

#### References:

- ANDER, P. et al. (1997) Preparation, Properties and Enzymatic Degradation of Biochemically and Chemically <sup>14</sup>C-Labelled Kraft Pulp, TAPPI 1997 Biol. Sci. Symp., October 19-23, 1997, San Francisco, CA, (ISBN 0-89852-695-7), pp. 473-482.
- GRABNER, K. et al. (1997) Evaluation of Oxidative Enzymes and Mediators in a Small Scale Using Chemically <sup>14</sup>C-Labelled Kraft Pulp, TAPPI 1997 Biol. Sci. Symp., October 19-23, 1997, San Francisco, CA, (ISBN 0-89852-695-7), pp. 373-382.
- ANDER, P. et al. (1998) The in vitro <sup>14</sup>C-labelled kraft pulp assay as used for evaluation of laccases and mediators intended for pulp bleaching. 7<sup>th</sup> Int. Conf. Biotechnol. Pulp Paper Ind. Vol. A, Vancouver BC, Canada, June 16-19, 1998., pp. A111-A115.

#### Acknowledgements:

This research was partly supported by EU DGXII-FAIR Programme, project no CT95-0805 (Oxidative Enzymes for the Pulp and Paper Industry, OXEPI). Part of the work was also carried out within the framework of Wood Ultrastructure Research Centre (WURC), a NUTEK competence centre at the Swedish University of Agricultural Sciences (<http://www-wurc.slu.se/>).

1. WURC (Wood Ultrastructure Research Centre), Dept. of Wood Science, Swedish Univ. Agric. Sciences, P.O. Box 7008, S-75007 Uppsala, Sweden. E-mail: paul.ander@trv.slu.se.
2. University of Technology Vienna, IBTM, Dep. of Mycology, A-1060 Vienna, Austria.

---

## P2. Press consolidation of composites with thermoplastic polymeric matrices

T. L. Andersen<sup>1</sup>

In a simplified model of the press consolidation technique, the following sequential steps can be identified: lay up, pre-heating under vacuum, forming, consolidation and cooling. Five basic pieces of equipment are required to fulfil the process cycle: A press, a pre-heat unit, a mould, a conveyor system and a control unit.

The press is a single active hydraulic press with a press force of 30 - 200 kN and a maximum press area of 1000 x 800 mm<sup>2</sup>. The piston with the crosshead is integrated in the bottom of the press and has a maximum press stroke of 400 mm. The speed of the crosshead can be adjusted from 0 - 100 mm/s. The crosshead will start at a speed of 100 mm/s, and it can be reduced at a given position to a more moderate closing speed. It is possible to stop the crosshead movement at a given force (pressure) or position. When the force or the position is reached an adjustable timer controls the time at which the material is pressurised.

In the pre-heat unit the material is conduction heated under vacuum in order to prevent/minimise the degradation of the matrix material and to remove the air (porosity) from the semi-raw material. The pre-heat unit consists of two 1300 Watt heaters. The design of the vacuum tool has been specially developed to handle postpreg semi-raw materials, where it is necessary to melt the thermoplastic matrix material in order to ensure a high level of fibre wet out in the consolidated laminate.

In the forming phase, the material has to stay hot for as long as possible to facilitate the rearrangement of the fibre reinforcement and matrix flow in the material. Fast and accurate handling of the material from the pre-heat section to the press is therefore necessary. The speed of the conveyor can be adjusted from 0 - 3 m/sec with a position accuracy of 1/10 mm.

The heating unit is set up for manufacturing of laminates with an area of 300 x 300 mm<sup>2</sup>. The mould parts consist of two 1300 Watt heated flat press plates placed at the stationary top part and attached to the crosshead, respectively. The PC/PLC control unit takes care of both the process parameters according to the fix values and automatic execution of the proces cycle.

The press facility has been used to manufacture glass fibre composites from a twill 3/3 weave based on a hybrid yarn. The hybrid yarn consists of 45 vol.% glass fibres and 55 vol.% thermoplastic polyethyleneterephthalate (PET) fibres. The porosity was determined to be below 2 vol.% in such a laminate, verifying its high material quality. Experiments with a 3D “hat” tool have also been performed.

Natural fibre laminates has been manufactured. Film stacking of “dry” jute fibre mats and thermoplastic polypropylene foils established the lay up. The porosity was determined to be approximately 5 vol.% in a jute fibre composite with random fibre orientation and a fibre content of 28 vol.% (41 weight %).

1. Materials Research Department, Risø National Laboratory, PO Box 49, DK-4000 Roskilde, Denmark

---

### **P3. Filament winding of composites at Risø National Laboratory, Denmark**

T. L. Andersen, B. S. Johansen and Aa. Lystrup<sup>1</sup>

Filament winding is mainly employed to produce continuous hollow parts with rotational geometry of various fibre/matrix combinations and with controlled fibre orientations. In the basic filament winding process, a continuous tape of resin impregnated fibres is wound over a mandrel to form the part. Successive layers with the same or different winding angles are added until the required thickness is reached. The winding possibilities fully depend on the winding machine and the control system. The two axes filament winding machine at Risø National Laboratory is based on a rotating mandrel and an application head with a feed eye moving along the rotating mandrel. The mandrel rotation and application head position is computer controlled to define the fibre coverage of the mandrel. The maximum diameter of a component is 500 mm and the maximum length is 1800 mm. The filament winding machine is placed in a heat chamber for maximum 80 °C. In a smaller chamber around the mandrel the temperature can be raised to approximately 400 °C.

The most common type of winding is geodesic placement of fibres on surfaces of revolution. In this type of winding the filaments will follow the shortest path on the surface and therefore not slip. The calculations relating to the geodesic fibre path, local wall thickness, and winding pattern are partly non-trivial, and must be performed repeatedly during a design stage. A computer program for the design of the filament wound structure is useful in this context. A software program "CADPATH" for computer aided design of filament wound structures has been developed at Risø National Laboratory with emphasis on user friendliness and portability. CADPATH calculates the winding pattern, fibre path and local wall thickness and fibre angle, on the assumption of geodesic winding and rotational symmetry. CADPATH can calculate uniform coverage patterns and a realistic wall thickness. CADPATH can be operated interactively with a user friendly menu system on a variety of platforms, in particular on standard, readily available personal computers.

The winding machine is attractive for fabrication of components with controlled fibre orientation, and it is often also used for winding flat test laminates with different fibre orientations. Unidirectional and cross ply test laminates can easily be manufactured from a single yarn or roving of the reinforcement. This is a cost-effective method for development of new material combinations, because the necessary quantity of surface treated material is relatively low, and it is possible to determine the most important material properties e.g. off-axis shear strength and tensile strength and stiffness in the 0° and 90° directions.

Prototype components wound at Risø National Laboratory include pressure vessels, centrifuge bowls, fly wheels, tubes and shafts. Material combinations include continuous glass and carbon fibres within a thermosetting or thermoplastic matrix material.

1. Materials Research Department, Risø National Laboratory, PO Box 49, DK-4000 Roskilde, Denmark

---

## P4. Natural fibre composites: Compaction of mats, press consolidation and material quality

T. L. Andersen and H. Lilholt<sup>1</sup>

Companies are interested in natural fibres not only because they are a renewable resource, but also because they have good strength and weight properties. High performance bast fibres from flax, hemp and jute can offer a real alternative to glass and synthetic fibres in polymer matrix composites. Semi-products are important means for efficient handling of fibres; mats of randomly oriented fibre configuration are typical semi-products for efficient fabrication of composites. Such mats influence not only the mechanical properties, but also the ease of handling of the material, the degree of compaction and thereby the maximum fibre contents in the laminate, as well as the material quality (low porosity). Economic mass production of components requires short processing times at low process temperatures. Natural fibres have limited heat resistance; use of thermoplastic polymer matrices with low melting temperature and low viscosity is therefore desirable. Some initial investigations of press consolidation of film stacked natural fibre composites have been conducted.

The compaction of jute fibre mats, composed of short fibres shows, that at a given compacting pressure a certain (maximum) value of fibre volume fraction for the fibre assembly is reached; for these dry mats the remaining volume is filled by air. Results shows that it is not possible, at increasing pressure, to compact the fibre assembly to an arbitrarily high volume fraction of fibres. These observations lead to the concept of a maximum fibre volume fraction, which can be reached by compaction of a short fibre assembly and thus can be obtained in composites.

For the investigated jute fibre mats a maximum fibre volume fraction  $V_f^{\max}$  of about 30 % is found (at the corresponding weight fraction  $W_f^a \approx 40$  weight %), and this is considered as a relative low value.

The press consolidation process for fabricating composites gives values for  $V_f^{\max}$  which are slightly higher than the corresponding values for compaction of dry fibre mats; a possible “lubricating” effect of the viscous matrix material may be involved.

A theory for the compaction of fibre mats is given based on the concept of a limiting  $V_f^{\max}$ , which leads to the definition of a structurally governed porosity content for composites,  $V_p^{\text{str}}$ . This in turn identifies a process governed porosity content  $V_p^{\text{proc}}$ , such that the total porosity content is made up of these two parts.

Experiments on jute/PP composites support the theory, and identify the process governed porosity at a level of 5 – 10 vol.% for the whole range of fibre weight fractions ( $W_f$ ) used. The total porosity content is low for  $W_f \leq W_f^a$  and is mainly process governed, while it is high for  $W_f > W_f^a$  and is dominated by structural porosity.

Improvements in composites material quality should therefore be aimed at process optimisation at low fibre contents ( $W_f \leq W_f^a$ ) and aimed at fibre mat improvement at high fibre content ( $W_f > W_f^a$ ).

The mechanical performance of composites will be restricted both by the rather low value of  $V_f^{\max}$  and by the strongly increasing structural porosity, and thus total porosity, at increasing fibre contents.

1. Materials Research Department, Risø National Laboratory, PO Box 49, DK-4000 Roskilde, Denmark

---

## P5. Autoclave consolidation of composites at Risø National Laboratory, Denmark

T. L. Andersen and Aa. Lystrup<sup>1</sup>

An autoclave is a process equipment with a chamber, where pressure and heat can be applied simultaneously. Furthermore, autoclaves used for manufacturing of fibre composites are equipped with a vacuum system, for evacuation of the material itself. The autoclave at Risø National Laboratory has the following main characteristics:

Internal diameter	800	mm
Internal length	1500	mm
Maximum temperature	530	°C
Maximum pressure	20	bar (2 MPa)
Maximum heating rates	10	°C/min.
Maximum cooling rates	15	°C/min.
Minimum vacuum level	2	mbar absolute

After lay-up of the pre-preg or post-preg materials, all thermosets and most thermoplastics are covered with various types of release and absorbent materials and then placed inside an airtight (vacuum) bag. The material is evacuated inside the bag and subjected to heat and pressure. The various types of vacuum bagging materials depend on the process temperature related to the matrix material. Some complications in bagging arise with thermoplastics, mainly because of the much higher process temperatures, up to 400°C, required to melt or soften the matrix in order to process the lay-up into a laminate.

The autoclave is attractive for fabrication of “reference” material of high quality during research and development of new materials and optimisation of process conditions or material performance. Autoclave consolidation can be characterised as an all-round but slow process. It is possible to cure fibre composites with a thermosetting matrix material and to melt and solidify composites based on a thermoplastic matrix. In both cases the pressure is used to shape and consolidate the material. The advantage of the process is the ability of manufacturing composite material with a very high and uniform quality, especially because it is easy to control the process parameters, and because the pressure is uniformly distributed even on components with a relatively complex shape.

The range of fibre composites processed in the autoclave at Risø National Laboratory is very wide. Fibres of glass, carbon, aramid, polyethylene (PE) and natural reinforcement fibres of wood, jute, flax and straw are some of the processed materials. Matrix materials include thermosets such as epoxy and polyester and thermoplastics such as polyethylene (PE), polypropylene (PP), polyethyleneterephthalate (PET), polyetherimide (PEI) and polyetheretherketone (PEEK).

The autoclave is also used for vacuum consolidation of composites. In this case, only the pressure difference between the vacuum inside the bag and the atmospheric pressure consolidates the material. High quality materials processed by vacuum consolidation are restricted to specially developed semi-raw materials.

1. Materials Research Department, Risø National Laboratory, PO Box 49, DK-4000 Roskilde, Denmark

---

## **P6. Lignin as natural binder**

Søren Barsberg, Jens Hassingboe and Peter Folting<sup>1</sup>

Two types of techniques which utilise lignin as a natural binder in fibre boards are explained and experimental results demonstrated. These techniques are steam activation of fibre lignin by a steam tight hot press and enzyme (laccase) activation of fibre lignin previous to hot pressing in an open press, respectively. It is demonstrated that promising mechanical - and swelling properties of boards are achieved by steam activation. In addition to an explanation of the mechanism by which enzyme activation of fibre lignin is achieved the nature of enzyme activation is discussed and it is demonstrated that lignin radical generation is a key feature.

1. Plant Fibre Laboratory, The Royal Veterinary and Agricultural University, Agrovej 10, DK-2630 Taastrup, Denmark

---

## **P7. Cultivation and enzymatic retting of flax in geothermal water in Iceland - A pre-project**

Sigurbjörn Einarsson<sup>1</sup>, Jón Guðmundsson<sup>2</sup>, and Kristján Eysteinnsson<sup>3</sup>

From our Sagas we know that flax has an important source of material for fabrics in Iceland in ancient time. After a long halt of flax cultivation an initiative was taken after the second world war to re-introduce flax cropping in Iceland. It failed since new materials like cotton and synthetic fibers were emerging on the market at that time. In recent years natural fibers have gained interest in Iceland as source of material for handcraft activity like weaving. Some of the weavers have cultivated flax for their own production. Their success has raised an interest for the creation of a large scale cultivation and pre-processing of flax in Iceland. Use of geothermal water, cheap and widely available in Iceland, for enzymatic tank-retting gives prospect of economical feasible retting process yielding a consistent quality of fibers.

Cultivation trials have been carried out in two consecutive growing seasons with different varieties of flax at different locations in Iceland. Alba and Aretmida gave the highest yield of raw fiber of about 1,3 t pr. ha.. The flax stems were retted enzymatically in geothermal water at 45°C by using an enzyme SP249, from NOVO Nordisk. The retting was carried out according to directions given by the enzyme producer. The retting process had to be kept going for 48 hours to give proper result in the scutching phase. Tenacity tests were carried out indicating little variance in strength with different retting time within interval of 48 – 72 hours. (Harvest for last the summer is currently under processing) Last summer's harvest is being processed and the results will be presented on a poster at the IENICA conference in May.

A creation of standard methods for flax fiber quality testing is a crucial issue for further development of our concept.

1. Technological Institute of Iceland, Keldnaholt, 112 Reykjavik
2. Agricultural Research Institute, Keldnaholt, 112 Reykjavik
3. Textile Technology Consulting, Stórhöfði 15 112 Reykjavík

---

## **P8. Fibres as filters for wastewater treatment**

Gina Fischer<sup>1</sup>

The standards imposed on industries that discharge heavy metals in their waste effluents are continually tightened due to increased industrial production and updated knowledge regarding the toxicities of heavy metals that enter the human food chain after accumulation in plants and animals (Förstner & Wittman, 1983). Conventional methods to reach imposed values of heavy metal concentrations in industrial effluents have shown their limits and are often extremely expensive. The biosorption phenomenon (Volesky, 1990) has provided an alternative treatment of industrial effluents from that of the traditional physico-chemical methods. It involves the use of natural substrate that are provided, for example, by agriculture (Kumar & Dara, 1982; Marshall et al., 1993), forestry waste product (Vazquez et al., 1994), micro-organisms (Brady & Duncan, 1994; Brady et al., 1994), humus (Kerndorff & Schnizer, 1980), lichens (Richardson, 1995) and mycorrhizal fungi (Galli et al., 1994). Biosorption is assumed to be metabolism-independent due to the use of non-living biomass. Metal ion uptake may therefore involve complexation, co-ordination, chelation, ion exchange, adsorption and inorganic microprecipitation according to the type of substrate (Volesky, 1990). In contrast, metal-ion binding to living cells occurs either through surface adsorption or through intracellular accumulation. Significant practical limitations to living biomass-employing methods to treat wastewater arise from the inhibition of the biomass growth when the metal cation concentrations are too high and/or when significant amounts of metal cation are sorbed. However, methods for water treatment that employ non-living biomass are not complicated by such considerations.

1. Plant Fibre Laboratory, The Royal Veterinary and Agricultural University, Agrovej 10, DK-2630 Taastrup, Denmark

---

## **P9. Trials with hemp for fiber production Denmark 1998**

Poul Flengmark<sup>1</sup>

At Danish Institute of Agricultural Sciences two experiments have been carried out at Flakkebjerg Research Center and at Roenhave Experimental Station during 1998.

The aim was to examine the potential yield of dry matter and crude fibre in five varieties of hemp grown at different plant densities and different row spacing, and to evaluate their seed production capacity.

Yields of dry matter obtained was 11 tons at Flakkebjerg and 14 tons at Roenhave.

Fibre yields increased from sowing rates of 8 kg/ha to 32 kg/ha and stabilized hereafter to 64 kg/ha.

At Flakkebjerg the varieties Fedora, Fedrina, Felina and Futura yielded about 3 tons of fibre/ha, while a German variety, Fasamo, which is shorter and earlier yielded about 2 tons/ha.

At Roenhave the fibre yield varied from 4 to 4.5 tons of fibre/ha depending of the variety, and for the sowing rates, about 4 tons of fibre was obtained with 8 kg seed/ha and increased to 4.4 tons of fibre/ha at the highest sowing rate.

Generally the fibre yield decreased a little at row distance of 48 cm in stead of 24 cm.

The seeds were only partly ripened, when the stems were retted in late September though sowing took place in the beginning of May. The seed yields ranged (depending of the variety ) from 300 to 600 kg/ha, but it has to be remembered, that the harvest season was very wet.

The trials will be continued .

*Key words:* Hemp; dry matter yield; fibre yield; varieties; sowing rates; row spacing.

1. Danish Institute of Agricultural Sciences, Department of Plant Biology, Research Center Flakkebjerg

---

## **P10. Determination of density, porosity, fibre and moisture content in plant fibre composites**

H. Frederiksen, T. L. Andersen and H. Lilholt<sup>1</sup>

The material quality of a natural fibre composite can be evaluated by the composite density, measured by the buoyancy method (Archimedes), and by the fibre and porosity content, measured by the matrix digestion method.

Plant fibre composites can, for example, consist of a fibre mat reinforcement in a thermoplastic polypropylene (PP) matrix. The total weight and density of the composite material is determined by measurement of the weight of the composite material in air and in water. In order to be able to correctly measure the weight of the composite material in water it is necessary to seal the porous surface; this is done by a thin paraffin coating. Repeated treatments in boiling xylene at 140°C leads to dissolution of the PP matrix material and paraffin coating. The natural fibres in the composite material are thereby released and it is possible to separate the matrix and fibre material by filtration of the solution. The fibre material is dried before measurement of its weight.

Calculation of the fibre volume content and porosity content is based on an exact knowledge of the density of both the fibre and the matrix material used in the composite material.

Determination of the densities is either performed by the buoyancy method (Archimedes) or by the pycnometer method. Some complications in density determination arise with plant fibres, because of the lumen inside the fibres and the possibility of small air bubbles on the fibre surface. Air bubbles on the surface can easily be removed, but it is important that the lumen also is filled with water during the weight measurement, and a vacuum procedure, which removes the air and replaces it with water, has therefore been developed. The matrix density is determined by a similar procedure. Measurements on the semi-product of PP-folis used for the lay-up is possible, but for semi-crystalline thermoplastics i.e. PP, the cooling rate during processing might change the crystallinity content and thereby the matrix density. Fabrication of pure matrix plates with the same process conditions as for the composite material has therefore been performed and the matrix density measured on samples of these materials.

Calculation of the fibre and porosity content in composite materials fabricated from flax, jute or wheat straw fibres within a PP matrix material has been performed successfully. The fibre volume fraction is normally in the range 20 – 30 vol.%, corresponding to a fibre weight fraction of 35 – 55 weight-%, and the porosity is normally in the range 2 – 10 vol.%. It is possible, due to the paraffin sealing coating on the samples, to determine the porosity in composites with very high porosity contents, up to 50 vol.%.

The moisture content in plant fibre materials has also been measured. The moisture content is normally in the range from 5 – 10 weight-% under “normal” laboratory conditions, and the rate by which the moisture content increases has been investigated by measurements on a vacuum dried plant fibre material.

1. Materials Research Department, Risø National Laboratory, PO Box 49, DK-4000 Roskilde, Denmark

---

## **P11. Evaluation of composite material quality by microscopy**

H. Frederiksen, T. L. Andersen and H. Lilholt<sup>1</sup>

In composite materials, based on e.g. plant fibres and a thermoplastic matrix material, a homogeneous distribution of the reinforcement fibres and a good fibre wet out by the matrix material is the basis for good material quality and thereby good performance of the material.

One way of controlling the composite material quality is optical microscopy on cross sections of the material. Samples from a composite plate or specimen are cut out from appropriate locations, and the samples are prepared by grinding and polishing of the cross sections.

At a magnification of 40 it is possible to study the composition of the composite material. The amount of matrix material can be controlled and it is possible to evaluate whether the amount of matrix material is too low or too high. In composite materials with too low matrix content it is possible to observe large porosity contents in the centre of the individual layers, and for materials with a very high matrix content matrix rich areas or layers are typical. The amount of reinforcement fibres can be estimated, and the fibre distribution can be evaluated qualitatively.

The individual reinforcement fibres and the fibre wet out can be observed at magnifications of 300 – 600. It is possible to determine whether the reinforcement is split into single fibres or whether the reinforcement fibres appear as bundles. Several plantfibres, e.g. jutefibre, have a lumen, which can be identified by microscopy; it is also possible to evaluate whether the lumen is filled with polymer matrix after composite fabrication.

Some plant fibre raw materials contain other parts than the “pure” plantfibres; e.g. flax-fibres are mixed with shives; these can be identified and quantified by microscopy.

Another important information is the degree of fibre wet out. Perfect fibre wet out is only achieved, if the matrix material surrounds each individual reinforcement fibre. This is especially a problem for composite materials based on a thermoplastic matrix material, because the viscosity of the molten matrix during processing is relatively high. Weave and mat semi-products manufactured from bundles of fibres will typically have unwetted fibres located in the centre of the bundles. Optical microscopy is very useful to detect unwetted fibres and can also be used to investigate the material for cracks in the matrix.

The results from the microscopy observations are compared with the determinations of the composite density, fibre volume fraction and porosity content.

Microscopy is always in use during materials and process development at Risø National Laboratory and it is also used to explain measured mechanical properties. Evaluation has been made of plantfibre composite based on jute, flax and straw, respectively

1. Materials Research Department, Risø National Laboratory, PO Box 49, DK-4000 Roskilde, Denmark

---

## **P12. Industrial crops in Denmark – economy and market potentials - with special emphasis on Hemp, Flax, Miscanthus and Reed Canary Grass**

Morten Gylling and Søren Marcus Pedersen<sup>1</sup>

Most of the Danish non-food crop production is based on potato starch for the paper industry, straw for fuel and oil seed rape for biofuels. The production of fibre crops is however still modest. A total of about 30 hectares of set aside land are applied for Miscanthus and Reed Canary Grass (RCG) and the area with Hemp and Fibre Flax covers less than 100 hectares in Denmark. The two latter have separate area support schemes and Miscanthus and RCG can be grown on set aside land with full compensation.

The production of industrial crops should, however be more than just a subsidised alternative to set aside on marginal land. In order to attract long term investments, the production of industrial fibre crops should be economic viable on conventional soils with subsidies at the same level as conventional crops.

This study emphasises on the production economy and market potentials of the annual crops, Hemp and Flax and in addition two perennial fibre crops, Miscanthus and RCG as fibre raw material for industrial use.

The method applied is system and costs analysis, which includes the costs of cultivating, harvest, storage, transport and separation of fibres for cellulose and fibre application. The aim will be to estimate a comparable cost/price for intermediate processed fibre raw material for industrial use at factory gate. In addition, the study includes a general analysis of the market potentials for industrial crops in Denmark and takes into account the changes, which are suggested in agenda 2000.

1. Danish Institute of Agricultural and Fisheries Economics, Toftegaards Plads, Gl. Koege Landevej 1-3, DK-2500 Valby

---

## **P13. Miscanthus propagation material supply and end use development**

J.J. Harvey<sup>1</sup>

BICAL is a new limited company dedicated to the commercial development of Miscanthus. Our shareholders are mainly UK farmers. We also have some corporate support and close association with similar companies in Germany the West Indies and USA.

We have developed commercial crop agronomy in UK, particularly mechanised rhizome lifting, storing and planting techniques, with funding from UK MAFF, DTI and EU EC5B funds. The crop has proven simple to manage and high yielding. In lowland southern England Miscanthus yields have been the highest of all biomass crops tested, and it is more efficient to grow and harvest in cost and energy terms than wood from trees and willow coppice. Herbicide and fertiliser requirements have been minimal, and it is easy to harvest and chop into useable forms, using existing farm machinery. Farmers find the crop attractive as it has been easy to manage, and existing farm machinery can be used for both planting and harvesting.

We are leading suppliers of planting material (rhizomes, microprops and seed), and involved in plant breeding. We are also experienced in importing and exporting plant material.

We are involved in projects which give carbon sequestration and fossil fuel substitution. These include heat and power projects via combustion, gasification and pyrolysis, and fibre uses as substitution for plastics and wood from trees. Biocomposites and paper pulp are end-uses we see as very promising.

We have planted a significant crop area in England this year, some by high-speed low labour techniques, and expect this to increase greatly in the next few years. Our first UK market products will be launched this year.

As an SME with commercial crop production expertise, end use researchers may be interested to have us as partners in development projects. We are particularly keen to co-develop large scale industrial productions, with manufacturing organisations.

Keywords: Miscanthus, rhizome supply, commercial propagation, end use development of fuel and fibre manufactured products.

1. Technical Director, BICAL, Easterhill Gardens, Kenn, Exeter, Devon EX6 7UG, England , Contact: Fax +44 (0) 1392 877003. E-mail JONHATKENN@aol.com

---

## **P14. Plant fibre morphology and surface characteristics observed by scanning electron microscopy**

P.V. Jensen and H. Lilholt<sup>1</sup>

Natural plant fibres and wood fibres are in most cases quite different in morphology and geometry from synthetic fibres like glass-fibres and carbon-fibres. These synthetic fibres are normally long, straight and have constant, near circular cross section and a generally smooth surface. In contrast, natural fibres seldom show such characteristics, and it is therefore necessary to observe and record the actual characteristic features, which may be of importance for the performance and the use of natural fibres, both on their own and in particular as reinforcing fibres for composites. In composites the natural fibres are normally bonded by a polymer matrix, and the adhesion/bonding between cellulosic fibres and a polymeric matrix is mostly not easily established due to the hydrophilic nature of cellulosic fibres and the hydrophobic nature of the polymer. Chemical treatment of the fibre surface is used to improve the bonding, and the morphology and geometry of the fibres may also add to the overall bonding strength established in natural fibre composites. The scanning electron microscope techniques are used to characterise the natural fibres in terms of morphology, geometry and interfacial bonding. The observations are presented as microphotos and allow a qualitative evaluation of the fibres.

The purpose is to compare the various plant and wood fibres, to establish standards for the characteristics and to develop a catalogue of natural fibres.

The observations of pure fibres give information on the diameter and cross sectional dimensions of fibres, the surface morphology, and the internal structure of fibre fractures.

The observations of failure zones in composites, after mechanical loading, give information on the failure paths through the composite and the interfacial adhesion between fibres and polymer matrix.

Actual SEM observations have been performed on fibres of jute, flax, hemp and birch. Observations have been performed on composites of jute fibres in a polypropylene matrix and composites of flax fibres in a polypropylene matrix.

1. Materials Research Department, Risø National Laboratory, P.O. Box 49, DK-4000 Roskilde, Denmark

---

## P16. Improvement of applicability of potato starch as non-food raw material

M.H. Madsen<sup>1</sup>

Potato starch has valuable quality properties not found in other types of starches, properties that are essential for the production of many non-food products. Although native potato starch has unique quality properties more than 50% of the starch is chemically and/or physically modified in order to fulfil functionalities for still more specific applications. These modifications are, however, undesirable due to high energy costs and the environmental pollution problems associated with chemical modifications. At present, the most important industrial properties of starches for non-food purposes are related to the following parameters: adhesion, film-formation, viscosity, gel strength, gel stability (retrogradation) and biodegradability. All these properties are directly determined by the molecular structure of the starch. Phosphorylation of starch significantly affects the physico-chemical properties of starch, e.g. the viscosity, gel strength, gel clarity, solubility and water binding capacity, which is advantageous for many industrial applications. Thus the phosphorylation level is a parameter which can be closely related to the functional properties of the starch. At present, *in vivo* produced starches with an increased phosphorylation level thus constitute a prime target for the development of novel starches. The significant difference between *in vivo* and chemical increase of phosphorus content is the specificity of the phosphorylation process and the retaining of the starch granules and thereby the crystalline nature of the starch.

The present project, financed by the program: "Forøget anvendelse af fornybare ressourcer til industrielle non-food formål (1997-2001)", aims at producing highly phosphorylated native potato starches with new physical properties to be used in new non-food products. During the project applicability of highly phosphorylated potato starch in different non-food productions will be tested. The *in vivo* increase in potato starch phosphorylation will be based on two synergistic approaches, the use of DNA-markers linked to starch phosphorylation in potato breeding with cultivated as well as wild *Solanum* ssp. and genetic modulation of the phosphorylation process in potato.

The project and results obtained so far will be presented at the poster.

1. Institute of Agricultural Sciences, Department of Crop Physiology and Soil Science, Research Centre Foulum, DK-8830 Tjele

---

## **P17. Composites made from biopolymers and natural fibers**

Norbert Mundigler and Birgit Herbinger<sup>1</sup>

One main area of research at the Department Natural Materials and Packaging Technology is the thermoplastic processing of composites with natural fibers from wood, hemp, flax, sisal or coco. Biopolymers such as starch, proteins, PLA or celluloseacetate are the preferred matrix material because they show a good compatibility with natural fibers and are environmentally friendly.

By this fiber reinforcement the mechanical properties of the matrix materials can be improved. With different material combinations it is possible to find individual solutions for many applications. Our department developed, for example, a loudspeaker cage from natural substances. For this application composite materials from celluloseacetate and natural fibers are meeting the list of requirements such as impact strength and resistance to temperatures up to 80°C. As reinforcing natural fibers coco and sisal showed the best processability.

Composite compositions, the required fiber properties, the processability and the resulting material properties will be discussed.

1. **IFA-Tulln**, Department Natural Materials and Packaging Technology, Konrad Lorenz Str. 20, A-3430 Tulln, Austria, Tel: +43 2272 66280 306, Fax: -303<http://ifa-tulln.ac.at> E-mail: [bherbing@ifa-tulln.ac.at](mailto:bherbing@ifa-tulln.ac.at)

---

## **P18. Long plant fibres for manufacturing of reinforced industrial products**

Lars-Bo Nielsen<sup>1</sup>

The poster is step by step showing the transformation from fibre materials to finished products. The raw material for the natural fibre mat are flax and PP fibres, mixed and carded before it is placed on a conveyor belt in the required thickness and width, and needled together to its final shape. The main flax fibre length is between 100 and 300 mm, and the PP fibre is 90 mm long.

The heating of the mat is done in an oven, where 200°C hot air is passing through the material. This method assures a fast and reliable (1 to 3 min) way of heating, without any risk of over heating causing excess damage to the fibres. After the heating, the material is placed in a tempered (100°C) pressing mould and a pressure of app. 4 N/mm<sup>2</sup> is applied. The pressure is retained for about 10 sec, after which the plate or products can be removed from the mould.

The poster shows an example of a test piece seen from both sides, and one piece is cut through in the middle. This test sample shows, how well the material can be shaped into very sharp corners without causing lack of material.

The poster shows other examples. A sandwich structure with a skin layer of Polyflax and the core material of Balsa wood. One of the skin layers has a cover of fabric material. All of the sandwich and fabric cover is manufactured in one operation without any excess glue or any other materials for bonding.

1. FORCE Institute, Dep. for Polymer Technology, Niels Jernes Vej 2 – 4, DK-9220 Aalborg Oe. Denmark, Phone: +45 96360806, Fax: +45 96350829, E-mail: [lbn@force.dk](mailto:lbn@force.dk)

---

## P19. Biologically based packaging materials for foods

Vibeke K. Nielsen, Grete Bertelsen, Claus J. Weber<sup>1</sup>

Our perception of plastics is changing drastically. Many current legislative, socio-economic, and social trends in Europe promote increasing use of renewable resources, waste recycling, and waste composting. Biopolymers produced from natural occurring organic raw materials provide a promising alternative to traditionally produced plastics, which are produced mainly from petroleum sources. The biopolymer is produced either based on natural occurring polymers, such as starch or protein or on raw materials produced by fermenting organic materials. Waste products from the agro-industry have *i.e.* been identified as good raw materials for the production of *i.e.* lactic acid, which can be polymerised to polylactate (PLA).

A major Danish, 4-year research program “Biologically Based Packaging Materials for Foods” was launched in January 1998. The project focuses on the whole area of production and application of biopolymers and aims at optimising the properties of biopolymers and tailoring them for food packaging applications.

This abstract presents an investigation of the influence of bio-film packaging on the storage quality of mushrooms. Mushrooms have a high respiration level, resulting in both a high consumption of oxygen and a concurrent high production of carbondioxide during commercial storage. Thus, mushrooms are commercially packed in a flexible, perforated cling film with an extremely low gas barrier. The high transmission of gasses through the film ensures a high level of oxygen inside the package, effectively avoiding anaerobic degradation of the mushrooms, which would be highly detrimental to the storage quality of the product.

Many of the flexible bio-films have very poor gas barrier properties. Thus, the storage quality of mushrooms packed in flexible bio-films based on renewable materials, originating from starch (wheat and maize) and PLA, was compared to the storage quality of mushrooms packed in commercial cling film. The mushrooms were stored either at 8 or 20°C. The quality, measured as colour, texture, maturity, and weight loss, was followed during 9 days of storage. The content of oxygen and carbondioxide inside the packages was furthermore determined.

In general, a greater decrease in oxygen and a higher increase in carbon dioxide within packages wrapped in bio-films compared to mushrooms packed in the commercial reference film was found. The colour of mushrooms packed in bio-films based on maize starch and PLA showed a comparable colour to that of the mushrooms packed in the reference film, whereas mushrooms packed in wheat starch films resulted in significantly discolouration of the mushrooms. The texture of the mushroom packed in bio-films were found to be more rubbery and a higher weight loss was also observed compared to mushrooms packed in the reference film. The higher weight loss of mushrooms packed in bio-films may be explained by a poor water vapour barrier of the bio-films, resulting in a greater water loss from the mushrooms compared to that of the reference film.

In conclusion, packaging of mushrooms in bio-films based on starch and PLA seems indeed feasible, however, some optimising of the bio-films for packaging of mushrooms must be considered. This work is currently taken place at the Department of Dairy and Food Science.

1. Department of Dairy and Food Science, The Royal Veterinary and Agricultural University, Rolighedsvej 30, DK-1958 Frederiksberg C, Denmark, E-mail: vkn@kvl.dk

---

## **P20. The characterisation and modification of wood and plant fibres**

Anne Bjerring Olesen, Mark Lawther and Ronny Torgilsson<sup>1</sup>

The Laboratory for Plant Fibre at KVL specialises in the bulk chemical and surface characterisation of plant fibres. The subsequent chemical modification of fibres to improve dimensional stabilisation and compatibility is also a research focus. This poster describes methods developed and utilised for the analysis of:

- Bulk chemical composition of the cell wall
- The monosaccharide sugar composition of structural polysaccharides
- The quantitative composition of lignin fractions (G / S / H ratios ).

Results for representative plant fibre materials are shown and the contrasting methods needed for different fibre types (eg wood versus non-wood) are emphasised.

Furthermore, methods of fibre chemical modification used at the laboratory are described and results of sample modifications are illustrated.

1. Plant Fibre Laboratory, The Royal Veterinary and Agricultural University, Agrovej 10, DK-2630 Taastrup, Denmark

---

## **P21. Fair 1697: Validation of raw material coming from kenaf**

Rafael Oliveros<sup>1</sup> et al.

The general aim of this project is “to set up the technical and economical frame of the use of kenaf raw materials in the manufacture of kenaf by-products”. The specific objectives are: General valuation of kenaf raw materials; Systemisation of the processes to be carried out with kenaf raw materials before the industrial processing; Use of kenaf semi-industrial products in final non-paper products; General valuation of the economical viability of kenaf-based final products; and Planning of chains of production/use of kenaf at a regional level.

The participants of the tasks are: KENINTER S.L. and Micelios Fungisem, S.A. (Spain); Istituto Poligrafico e Zecca dello Stato (Italy); The BioComposites Centre (United Kingdom); ATO-DLO (The Netherlands) and BalkanExport (Greece). This consortium is developing: research tasks using the kenaf species in different fields as the varietal valuation; the systemisation of physical (separation, compaction, etc.) or chemical processes (structure modification) in order to homogenise the agricultural raw materials before the industrial process; the use of products of multiple applications (composite, non-wovens, etc.), as well as a substrate for special agricultural productions (edible fungi crop)

In short, we are trying to cover the range of potential uses for kenaf, including technical aspects, economical valuations, evaluation of potential markets and the planning of possible development of kenaf at a regional level.

The main results to date are: Varietal influence on fibre quality has been tested; The technical efficiency of pretreatments for separating fibre has been verified; Application of kenaf core in the production of substrates for producing edible fungi has been successful. Studies of production processes for new products derived from kenaf are ongoing.

1. KENINTER S.L. Madrid.Spain, Phone: ++34-918457398. Fax:++34-915615626, E-mail: [rolivea3@teleline.es](mailto:rolivea3@teleline.es)

---

## **P22. Fibres from flax and hemp for mat-production specially insulation purposes**

Bodil Engberg Pallesen<sup>1</sup>

Industrial use of plant fibres in the industry is a relative new area. During the recent years research is going on all over the world, in order to find competitive applications for the industry. The goal is to substitute synthetic fibres like plastic, glass and mineral fibres. Use of plant fibres in the industry could assure a sustainable development towards utilisation of renewable resources.

Plant fibres have a number of promising properties, covering environmental, technical and industrial properties. Especially flax and hemp are very interesting due to their high fibre strength, high content of cellulose, high absorbic properties and high insulation properties.

Department of Plant Production, at The Danish Agricultural and Advisory Centre, has developed new methods of handling flax and hemp fibres from field to final product. Specially products like fibre mats for insulation purposes has been one of the main targets. The department of Plant Production has developed a so call "shortfiber-process line", where the retted flax- or hemp fibres are shortened to relatively short fibres at an average length of 20 mm. The defibration technique has a high capacity and is very cheap. The fibres from flax and hemp are formed into mats through a special airforming-technique. The mats are suitable for many purposes such as insulation boards, composites etc.

The efforts are concentrated in building up a new industry producing fibre mats from Danish grown flax, and in the future Danish hemp. So far an area of 12 hectares with fibre flax, grown in the southern part of Denmark, seem to be the first step towards a new production based on Danish fibre plants.

1. Department of Plant Production, The Danish Agricultural and Advisory Centre, Udkaersvej 15, DK-8200 Aarhus N. Ph: +45 87 40 50 00, fax. +45 87 40 50 90, e-mail: [bdp@lr.dk](mailto:bdp@lr.dk)

---

## P23. Geometrically modified bio-fibers through enzyme treatment

Bert Pettersson<sup>1</sup>, Ulla-Britt Mohlin<sup>1</sup>, Gunnar Henriksson<sup>2</sup> and Mikael Lindström<sup>1</sup>

One of the big challenges with bio-fibres is to master the intrinsic scatter of quality, size and shape between fibres from the same source. This is of different importance in different applications. To make strong papers, we need long and strong fibres but for fine printing surfaces we need short fibres where strength is of minor importance. In composites it is important to increase the fibre content as fibres often are cheaper and lighter than the polymer matrix and they give function. It is known that more fibres can be added if they can be oriented and have a uniform size. The L/d ratio of the fibre is also important for the composite performance.

Natural fibres often display regularly repeating nodes along the fibre axis. These nodes contain wood polymers, which are less ordered than the rest of the fibre. This study was performed in order to study the possibility to swell fibres in these nodes and further to cut them at the nodes. Cutting at the nodes would lead to shorter fibres but less scatter in fibre size distribution. Results from studies of different enzyme cocktails upon fibres from Norway spruce, *Picea abies* L. Karst. and flax, *Linum usitatissimum* is presented.

In paper production, long fibres are a disadvantage causing flocculation and uneven fibre distribution. Shorter fibres give better formation. Examples from the EUROFEX experimental paper machine will be presented.

1. STFI, Box 5604, SE-114 86 Stockholm, Sweden
2. Department of Pulp and Paper chemistry and Technology, KTH, SE-100 44 Stockholm, Sweden

---

## **P24. Quantitative non-destructive characterisation (NDC) of plant fibre composites**

Jørgen T Rheinländer, Emmanuelle Cendre and Kaj K. Borum<sup>1</sup>

Plant fibre composites may offer similar mechanical performance as conventional (glass fibre) composites, although their impact strength is somewhat less. Since plant fibre composites constitute a relatively new group of materials, the limitations imposed on the mechanical performance due to flaws are not well known. Thus, the subject of this presentation is the variety of flaws arising from different manufacturing procedures for plant fibre composites. Of special interest is the importance of the flaws for the mechanical properties and their detection and quantification by NDC techniques. The basis of this work is a carefully selected variety of samples with intended manufacturing defects. The samples were characterised quantitatively by radiography, ultrasound and thermographic techniques. The techniques applied were selected based on an introductory performance study on conventional fibre composites. Subsequently, some of the plant fibre composite samples were characterised by a number of destructive characterisation techniques, including quantitative microscopy studies. Other (identical) samples were selected for mechanical testing.

Based on the results it is concluded that the NDC techniques can provide quantitative data for an assessment of manufacturing variables, such as e.g. moisture content of the fibres, fibre orientation and porosity. The effect of the different defects characterised by destructive and NDC techniques is described by the correlation to the mechanical testing results.

1. Materials Research Department, Risø National Laboratory, POB 49, DK-4000 Roskilde, Denmark

---

## **P25. Physical properties of linseed (*Linum usitatissimum* L.) fibres**

H. Rennebaum<sup>1</sup>, W. Diepenbrock<sup>1</sup>, E. Grimm<sup>1+2</sup>

Beside their use in textile products, plant fibres are increasingly applied in composite materials. One of the crucial points is an adequate analysis of fibre performance. We report on three aspects, related to the assessment of fibre quality by mechanical tests:

i) Due to the cellular structure of plant fibres stress-strain curves are geno- and phenotypically specific.

Measurement of tensile strength is recommended at two grip distances, considering breaks through complete cell walls and along the pectin lamellae.

ii) Water vapour sorption and desorption exhibit a very rapid response to changes of humidity. However, sorption dependent mass increase is low. Tensile strength tends to decrease in moist environment.

iii) The precision of mechanical tests is strongly affected by the determination of the cross-sectional area of the specimen. Recording the diameter of plant fibres by a two-axial laser micrometer is critically reviewed.

Results will be summarised by methodical suggestions for plant fibre handling.

1. Martin-Luther-Universität Halle-Wittenberg, Landwirtschaftliche Fakultät, Institut für Acker- und Pflanzenbau, Ludwig-Wucherer-Str. 2, D-06099 Halle (Saale), Germany
2. The author, who will present the poster

---

## P26. Properties of wheat straw and beechwood fibre fraction prepared by wet oxidation and enzyme treatment

A.S. Schmidt<sup>1</sup>, J.M. Lawther<sup>2</sup>, S. Hvilsted<sup>3</sup>, A.B. Thomsen<sup>1</sup>

Lignocellulosic biomass like residues from agricultural and forestry crops *e.g.* straws and wood chips are potential raw materials for industrial production of several high-value products in particular biofibres. In fibreboard production, there is increasing interest to find alternative ways of achieving adhesion in fibre composites and boards to eliminate or reduce the use of synthetic adhesives. Two approaches have been taken to increase the reactivity of the lignin compound in the lignocellulosic material in order to improve its adhesive properties and use it as a natural binder.

Wet oxidation (WO) combined with alkaline hydrolysis has proven to be an efficient method for pre-treating agricultural crops for conversion purposes as it has a large effect on the lignin compound. Hence, this process was investigated to see if this effect increased the adhesive properties of lignin. As WO removed most hemicellulose and non-cell wall materials, moisture problems might also be avoided or limited in the fibre composite and board. An enzyme treatment (ET) with laccase (developed in collaboration with Novo Nordisk A/S) has been shown to increase the auto-adhesion of wood fibres by creation of long living free radicals in the lignin component. This activates the lignin polymer by loosing the overall rigid structure, allowing flow during composite formation or perhaps by promotion of radical-radical cross-linking between fibre surfaces. The **precise** mechanism is not yet understood and is under investigation.

In this study, two very different raw materials, wheat straw and beechwood, were used to evaluate the potential of the two pre-treatment processes (WO and ET) for generating fibres with high adhesive properties. The fibres were evaluated by their chemical composition, degree of acetylation, reactivity, and Fourier Transform Infrared (FTIR) spectroscopy. The results indicated (as expected) that the two different raw materials reacted very different in WO and ET. The chemical composition did not change much by ET, whereas considerably changes were observed for WO giving fibres highly enriched in cellulose. WO removed much of the hemicellulose (80%) together with a large portion of the lignin. By ET, most material remained as a solid. For both materials mainly non-cell wall material had been solubilised during ET, whereas all cellulose remained in the solid fraction (99.5%). For wheat straw, the measured degree of acetylation indicated that both treatments opened the material in such a way that more hydroxyl groups became available on the surface. For the treated material, the reaction rate was also higher compared to the untreated. ET generally gave a more reactive surface than WO due to solubilisation of lignin and hemicellulose during WO. FTIR spectroscopy showed a complete loss of the ester carbonyl stretching and the corresponding asymmetric C-C-O stretching of ester in WO materials. However, FTIR could not detect the observed effect of ET on beechwood.

1. Plant Biology and Biogeochemistry Department, Risø National Laboratory, P.O. Box 49, DK-4000 Roskilde, Denmark
2. Plant Fibre Laboratory, The Royal Veterinary and Agricultural University of Denmark, Agrovej 10, DK-2630 Taastrup, Denmark
3. Condensed Matter Physics and Chemistry Department, Risø National Laboratory, P.O. Box 49, DK-4000 Roskilde, Denmark

---

## **P27. AIR 3-CT94-2000: High-performance biocomposites with improved durability and dimensional stability from non-toxic chemically modified lignocellulosic fibres**

Rune Simonson<sup>1+2</sup>

Lignocellulosic fibres derived from wood and annual plants are known to be strongly upgraded biologically (resistance to fungi and insects) and technically (dimensional stability and resistance to weathering) when the cell wall components are chemically modified by introduction of bulky, less hydrophilic groups such as the naturally occurring acetyl groups. By this upgrading, renewable fibres with different origin are transformed into a high-quality non-toxic fibre resource. The strongly improved properties gained by chemical modification such as acetylation enables the manufacturing of moulded fibre composites which can be used in applications where traditional lignocellulosic fibre based products have shown insufficient technical properties and may have been replaced by e.g. plastics.

The general objectives of this project was to produce chemically modified fibres preferably achieved by acetylation and manufacture high-performance flat as well as complex-formed moulded biocomposites from the fibres and to evaluate the biological and technical properties of the industrially produced composites as well as their market potential.

Commercial softwood fibre (mainly spruce) and beech wood fibre pulps used for manufacturing of medium density fibre boards were included in the study as were pilot plant manufactured pulps of aspen wood, wheat straw and waste wood from an intermediate forest trimming. Recycled paper was also used. Different chemical modifications were applied including acetylation, maleoylation, succinylation, phthaloylation, silylation, acrylation, oxidation with sodium periodate and treatment with an isocyanate (TMI). Heat treatment of wood wool was also carried out. Only acetylation was conducted in a large scale operation of 100 kgs batches, the rest of the treatment being performed in laboratory scale. The treated fibres were used to form flat laboratory boards which were tested according to EN standards.

Taking into account the results obtained in different testing, flat boards and complex-shaped products produced from acetylated fibre showed the best results with respect to biological and mechanical properties. Acetylation also showed the lowest level of cellulose degradation. Although many of the other modifications are still under development, only one of these treatments, namely modification with TMI, seems to give a level of improvement comparable to that obtained by acetylation. However, the treatment is technically more complicated and the TMI chemical is very expensive.

Acetylated boards showed a thickness swelling of 1.8% (EN 317, 24H water immersion) and a remaining thickness swelling after EN 321 of 0.1%, the residual internal bond strength (IBS) corresponding to 80-90% of the dry strength. The decay resistance in laboratory tests was excellent with no weight losses for the acetylated boards according to prENV 12038. This good resistance to degrading fungi was further confirmed in field tests at seven international sites provided that the level of acetylation was about 20% calculated as acetyl content.

Acetylated fibres of different origin were used to produce flexible mats also containing thermoplastic fibres (5-8%) and powdered phenol-formaldehyde resin (10%). The fibre mats were used to industrially manufacture products such as moulded flat boards for painted doorskins, flat boards with decorative layer for flooring, exterior cladding and wet-room panelling. Complex-shaped products were produced in the form of automotive rear shelves, roof tiles and toilet lids. All products showed greatly improved properties compared with standard products.

1. Chalmers University of Technology, Sweden, Co-ordinator
2. Other participants:
  - Stichting Hout Research, SHR, The Netherlands
  - Technical Research Center of Finland, VTT, Finland
  - The Royal Veterinary and Agricultural University, KVL, Denmark
  - The BioComposites Center, Wales, Great Britain
  - Rijksuniversiteit Gent, Laboratorium voor Houttechn., Belgium
  - AB Kangre, Sweden
  - SkåneGripen AB, Sweden

---

## **P28. Development of a new coated membrane textile using natural plant fibres**

D. Stewart<sup>1</sup>, N. Burford<sup>2</sup>, W. Jabs<sup>2</sup>, W. Hoeck<sup>3</sup> and M Rowan<sup>4</sup>

### ***Introduction***

Currently the main fibre-coating combination used in architectural fabric structures (awnings, marquees, stadia, airports) is polyester coated with PVC. Both of these have inherent problems: polyester is a purely synthetic fibre derived from mineral oil and PVC; a chlorine containing polymer, is subject to increasing legislation relating to manufacture, fabrication and disposal. The use of PVC is likely to be limited, even phased out in the future. There are currently no low cost, environmentally sustainable alternatives which display similar performance characteristics. The aims of this research project are to establish the efficacy of a fabric with a natural fibre substrate and a non-chlorine containing, polyurethane-based coating that could provide the physical and mechanical properties required for its application as a membrane in tensioned fabric structures.

### ***Experimental***

Woven flax (three densities) and jute (one density) were treated with a single formulation of halogen-free, urethane coating at a range of dilutions both with and without pre-wetting of the fabric. The coating was applied by several different methods, such as manual brush, callendered, rolled application etc. The coated and uncoated samples were tested with regard to physical and chemical properties and compared to the current industrial standard, PVC-coated polyester fabrics.

### ***Conclusions***

Polyurethane coatings were shown to be amenable for use with woven cellulosic materials.

In the case of flax fibre covalent linkage of the polyurethane to the cellulose was evident and is predominantly at the cellulose C<sub>6</sub> carbon.

Coating with a polyurethane coating inhibited fungal degradation of the matrix flax fibre

Co-blending of specific high strength synthetic/natural fibres would be required to increase tensile strength to values similar to high strength PVC fabrics.

The highest strength to weight ratio coated flax/jute fabrics tested only developed 50% of the strength to weight ratio of lowest strength to weight PVC-coated polyester fabrics.

The study has indicated that the coating application process most likely to develop the highest strength to weight ratio of a coated cellulosic fabric would be equivalent to a proofing process.

1. Unit of Plant Biochemistry, Scottish Crop Research Institute, Dundee DD2 5DA, Scotland, UK
2. Lightweight Structures Unit, University of Dundee, Dundee, DD2 1HN, Scotland, UK
3. Tec-Knit, Lönswg, POB 131 D-46414 Rhede-Krechting, FRG
4. Wilkies Industrial Textiles Ltd, Kirriemuir, DD8 4RL, Angus, Scotland, UK

---

## P29. Conversion of plant residues to high-value products

Anne Belinda Thomsen and Anette Skammelsen Schmidt<sup>1</sup>

The cell wall of plants (leaf, stem, wood) consists of three main components: 40% cellulose, 35% hemicellulose and 15% lignin. Cellulose and hemicellulose consist of sugar components, which are bound together - in one polymer. These sugars form the majority of all organic carbon on Earth representing a massive resource of raw material. The cellulose is very straight and closely packed and has therefore a substantial tensile strength. The hemicellulose is much more branched and has no strength. The lignin is the glue, which holds the components together, and act as a barrier for biological degradation.

Several high-value products can in this way be produced from plant residues, however, a fractionation is needed for efficient utilisation. For this purpose, Risø apply two different pre-treatment techniques: wet oxidation and steam explosion. These processes solubilise mainly the hemicellulose and leave the cellulose as a solid. The resulting sugar solution can be converted to a variety of products *e.g.* xylitol, lactic acid and ethanol by fermentation. The remaining cellulosic fibres can also be used for fermentation, however, the polymeric structure have to be degraded with *e.g.* enzymes, before the sugars can be fermented to other high-value products. Due to their substantial strength, cellulosic fibres can be also used as reinforcement fibres in composite materials and fibreboards.

1. Plant Biology and Biogeochemistry Department, Risø National Laboratory, PO Box 49, DK-4000 Roskilde, Denmark

---

### **P30. Wet-oxidised wheat straw used as reinforcement for polypropylene composites**

A.B. Thomsen<sup>1</sup>, A.S. Schmidt<sup>1</sup>, H. Toftegaard<sup>2</sup>, W.B. Pedersen<sup>3</sup>, A. Woidemann<sup>1</sup>, H. Lilholt<sup>2</sup>

Natural fibres based on cellulose are finding increasing use in materials and industrial products creating more environmentally friendly, renewable and CO<sub>2</sub> neutral products. Their physico-chemical properties are suitable for composite applications, thus allowing replacement of traditional fibres such as glass, asbestos, and carbon. Due to the low density of cellulosic fibres, natural composites are widening the spectrum of available load-bearing materials and could generate composites with better specific stiffness and structural superiority. In lignocellulose, such as wheat straw, cellulose only constitutes 40% of dry weight, and up to 35% is hemicellulose. The hemicellulose will create higher hygroscopicity giving a less stable composite and thus limit applications. Wet oxidation treatment is very efficient in hemicellulose solubilisation leading to high quality cellulose-rich fibres.

Within this study a small series of “natural” composites, based on wet-oxidised wheat straw fibres and polypropylene (PP) matrix, are fabricated and characterised. The properties of importance are the strengthening and stiffening contribution of the composite given by good fibre stiffness and strength and a matrix well bonded to the fibres. Hence, the wet-oxidised wheat straw was characterised in terms of chemical composition, surface reactivity, and cellulose chain length. Composite laminates were fabricated from “mats” of wheat straw and foils of PP by hot pressing in an autoclave. The composite laminates were characterised by density, microstructure, volume fraction of fibres and matrix as well as porosity and mechanical properties.

The wet-oxidised wheat straw was highly enriched in cellulose (up to 75% w/w) as 80% of the original hemicellulose and 45-70% of the original lignin had been removed resulting in bleached fibres. The wheat straw fibres acted as reinforcing fibres in the composites, giving an increased stiffness. The composites have fibre contents of about 30% v/v and rather high porosity contents of 25 to 35%, which was due to non-optimised composite fabrication conditions. Wet oxidation reduced the cellulose chain length at high oxygen pressure. However, this had only a minor effect on the stiffness of the fibre composites. The mechanical properties of wheat straw composites (short fibres) showed tensile strength up to 18 MPa and stiffness up to 3 GPa. These properties are comparable to those of flax composites (long fibres) but lower than those of jute composites (long fibres).

1. Plant Biology and Biogeochemistry Department,
2. Materials Research Department,
3. Condensed Matter Physics and Chemistry Department, Risø National Laboratory, PO Box 49, DK-4000 Roskilde, Denmark

---

### **P31. Mechanical characterisation of plant fibre composites**

H. Toftegaard and H. Lilholt<sup>1</sup>

The mechanical properties of plant fibre composites are characterised, both to evaluate the performance and efficiency of plant fibres as reinforcement in composites, and to establish the (overall) mechanical properties of the plant fibre composites. Such properties are important in an evaluation of the potential for technical applications of the composites, especially for load bearing constructions.

The basic mechanical properties of materials, and thus in particular plant fibre composites, are the stiffness, strength and deformation behaviour.

The stiffness is a measure of the resistance of the material to deform under a given load, and is defined as the stress (load per unit area) needed per unit of deformation.

The strength is a measure of the load-bearing capability of the material, and is defined as the stress needed to break the material.

The deformation behaviour is a general measure of how the material responds to loading, and is recorded as the monotonically increasing stress needed to continuously deform the material to ever increasing amount of deformation. The curve describing the deformation behaviour is called a stress-strain curve.

During the general loading of the material several, often small, cracks can form in the material; such cracking gives off energy in the form of sound. With appropriate equipment it is possible to record such acoustic emission.

Several plant fibre composites have been tested to record their mechanical properties. From the stress-strain curves the stiffness and strength values are calculated. Typical values for the composites are given and compared to glassfibre-composites:

Plantefibre composite	Stiffness GPa	Strength MPa
Jute/polypropylene	4-8	25-50
Flax/polypropylene	4-6	25-35
Wheat Straw/polypropylene	2-4	13-18
Glassfibre/polypropylene	4-6	35-55

The stiffness and strength of the fibres themselves can be calculated from these data, based on composites theory, and typical values for fibres are:

Fibre	Stiffness GPa	Strength MPa
Jute	53	360
Flax	44	290
Wheat straw	41	280
Glass	70	3000

---

## **P32. Fibre stiffness and strength estimated from tests on composites**

**H. Toftegaard and H. Lilholt<sup>1</sup>**

Natural fibres have a potential to be used with binders to form good composite materials. The properties of the composite depend not only on the properties of the fibres and the binder (matrix) but also on the quality of the interface between the individual fibres and the matrix. Treatments to improve the properties of the fibres or the quality of the interface are difficult to evaluate. Mechanical tests on single fibres or fibre bundles are difficult and time consuming to perform. Mechanical tests on composite materials, however, are relatively easy to perform. Here the problem is to derive the fibre and interface properties from the composite properties.

In this study a series of composites consisting of jute fibres in a polypropylene (PP) matrix as well as flax fibres in a PP matrix were fabricated and characterised. Composite laminates were made from mats of jute or flax fibres together with foils of PP by hot pressing in an autoclave. The composite laminates were characterised by volume fraction of fibres, matrix and porosity, as well as mechanical properties in two perpendicular directions of the mats. Furthermore the mechanical properties were determined for the pure PP matrix.

Both the composite stiffness and strength are assumed to be a function of fibre and matrix properties (stiffness and strength, respectively) as well as a function of the volume fraction of fibres, matrix, and porosity. Besides the unknown fibre property the stiffness and strength functions each contain two parameters describing the influence from fibre orientation and from porosity. To determine these parameters and the fibre stiffness and strength data are needed for a set of composite laminates with the same fibre type and a (wide) range of different porosity levels. This was accomplished by varying the number of PP foils in the composite.

With this approach the fibre stiffness and strength were estimated for three different types of jute mats and eight different varieties of flax mats. The approach is not able to distinguish between the influence from fibres and from fibre/matrix interface on the composite stiffness and strength. This is shown clearly by the results for nominally identical flax fibre mats with an area weight of 300 g/m<sup>2</sup> and 600 g/m<sup>2</sup>. The apparent stiffness and strength is much higher for the fibre mats with the low area weight. For mats of equal area weight it seems that the jute mats and the best varieties of flax mat have an equally high level of stiffness (50 GPa) and strength (350 MPa). For flax mats the following parameters seem to give stiffer and stronger mats: no or little retting (as opposed to a high degree of retting) and a high degree of purity (a low content of shives).

1. Materials Research Department, Risø National Laboratory, PO Box 49, DK-4000 Roskilde, Denmark

---

### **P33. Optimisation of the agrofibre quality by an innovative biotechnological approach**

Marcel Toonen, Michel Ebskamp, Iris Tinnenbroek, Andries Koops and Hans Marvin<sup>1</sup>

Since social developments stimulate the use of renewable sources, it is expected that the market for agrofibre raw materials will grow extensively. More specific, novel applications within for example the car industry will lead to an increased sale of agrofibres. To anticipate to these developments, the DLO Centre for Plant Breeding and Reproduction Research in collaboration with the DLO Institute for Agrotechnological Research (ATO-DLO) has initiated a strategic programme aiming at the identification and optimisation of key factors determining the fibre quality of flax (*Linum usitatissimum* L.).

A number of selected flax cultivars are used to study molecular key factors determining cellulose biosynthesis and xyloglucan and pectin metabolism. As a first step in this study 1 000 expressed sequence tags from a flax cDNA library were sequenced. Genes of interest will be further analysed e.g. by reintroduction into flax plants. The function of the introduced and related genes will be studied and plant prototypes which will contain improved fibre quality will be produced. To this end a transformation protocol for flax is being developed.

1. Centre for Plant Breeding and Reproduction Research (CPRO-DLO), P.O. Box 16, 6700 AA Wageningen, the Netherlands, E-mail: [m.a.j.toonen@cpro.dlo.nl](mailto:m.a.j.toonen@cpro.dlo.nl)

---

## **P34. A route for the manufacture of biodegradable composites from renewable resource materials**

Nick Tucker and Shen Yon Teo<sup>1</sup>

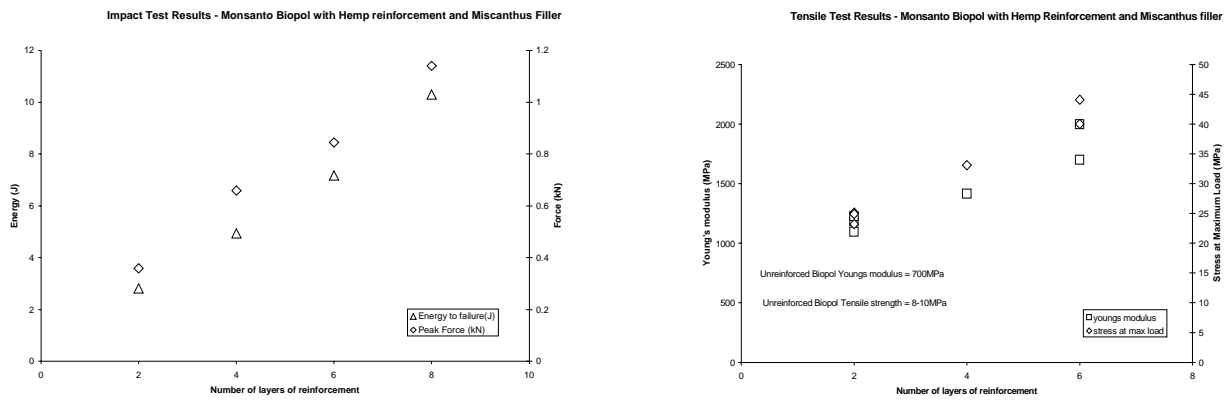
This paper describes a method of manufacturing biodegradable composite products from renewable resource materials. Legislation is forcing industry to analyse the way we design the life cycle of a product beyond the need of the first user, to subsequent users and ultimately to end of life disposal. A typical example of this is the need to reduce the amount of polymeric material, essential to the production of the modern fuel-efficient motor car, which finds its way to landfill at the end of the vehicles working life. Reinforcement materials such as hemp, jute, flax, sisal and bamboo have all been tried in various manufacturing studies. This work has usually involved the use of non-renewable resource thermoset resins and traditional processes such as resin transfer moulding (RTM). Renewable resource thermoset resins based on soya beans have been to make glass reinforced foam cored composites by John Deere & Co, but only so far on a pilot scale. Much more readily available are thermoplastic renewable resource biodegradable plastics. An example of such a material is Monsanto Biopol, made from beet sugar by the action of bacteria. This material was compounded with chopped miscanthus fibre as a renewable resource filler .

In the group of experiments described in this poster, a new process has been devised to impregnate the thick natural fibre felts (typically 450gsm) with viscous thermoplastic melts. The process used was a two stage extrusion compression. The Dasset compression extruder was loaded with Biopol and 15w% chopped miscanthus fibre, layers of fibre were placed in the mould and the filled matrix extruded onto it. Further layers of reinforcement were then added and the mould closed to consolidate the product. Figure 1 shows the extrusion compression rig, with the injection moulding barrel mounted.



**Figure 1** *The Dasset compression extrusion rig*

This method proved successful in manufacturing plaques with up to 8 layers of 450gsm hemp felt. It is now the subject of a patent application.



**Figure 2** Impact and tensile test results for Biopol/Hemp/Miscanthus polymers.

1. Warwick Manufacturing Group Advanced Technology Centre, University of Coventry, Coventry, CV4 7AL, United Kingdom