COST E50

"CELL WALL MACROMOLECULES AND REACTION WOOD" (CEMARE)

WORKPLAN

A. Background

The major components of plant cell walls are cellulose, hemicelluloses and lignin. A cellulose chain consists of about 10,000 glucose units. In general, 30-40 parallel cellulose chains associate to form microfibrils containing crystalline and amorphous parts. The orientation of microfibrils in the various cell wall layers determines the strength properties of individual fibres and solid wood. Moreover, it is a key parameter for the biomechanical function of wood in the living stem.

Trees control the shape of their stems through the generation of growth stresses during the process of wood formation. In situations demanding high orientation control, trees produce the so-called reaction wood (RW), defined by the International Association of Wood Anatomists (IAWA) as "wood with distinctive anatomical and physical characteristics, formed typically in parts of leaning or crooked stems and in branches, that tends to restore the original position of the branch or stem when it has been disturbed; also known as tension wood (in deciduous trees) and compression wood (in conifers)". This definition combines a functional and a structural aspect of RW, but also refers indirectly to the problems associated with RW occurrence: namely heterogeneity of physical and mechanical properties within wood products, often leading to instability in use and rejection by the end-user.

Wood fibres have a complex ultrastructure and are composed of several cell wall layers. These cell wall layers vary in their respective amounts of cellulose, hemicelluloses and lignin. The chemistry and ultrastructure of this complicated network of wood components determines the properties of the resulting lignocellulosic fibre of both annual and perennial plants, as well as the amount of longitudinal growth stress generated during cell-wall maturation. This is the result of the biosynthetic and biochemical processes during cell wall formation. The various types of RW represent extreme cases of macromolecular and ultrastructural organisation: compression wood is characterised by high lignin content and high microfibrillar angle, while tension wood has little lignin and a low microfibrillar angle. Approximately half of the angiosperms species produce tension wood where the secondary wall is partially replaced by a so-called "gelatinous layer" from which lignin is absent and made up of axially oriented cellulosic microfibrils.

The final fibre properties are of great importance for the quality of pulp and paper as well as timber and sawn products. More information on the variability of cell walls in different wood species and new ideas on how modifications can be made at the ultrastructural level (scale from 1 nm to about 500 nm resolution of the fibre) are required in order to develop new cellulose and wood-based products and composite materials, to improve production processes and thus, to optimise the use of the industrial potential of wood fibres.

In trees and other woody plants, the biosynthesis of lignin has been modified by genetic engineering to change the enzymatic machinery. Different treatments, such as high temperature drying and microwave treatments, modify cell wall chemistry and wood properties. The structure of lignin in certain trees has been altered producing fibres that are easier to pulp, requiring less chemical and energy inputs. In contrast, the content of lignin should be increased and its structure should be modified in order to grow trees being more resistant to wind, rain, decay and pathogens as well as to produce stronger timber and resistant solid wood products. All these modifications are likely to influence growth-stresses generation and RW production, due to the possible role played by lignification.

Selective removal of cellulose, hemicelluloses or lignin from lignocellulosic fibres with specific enzymes may be used for studying fibre structure at all levels of resolution and to modify their technological properties. Polysaccharide hydrolysing enzymes (cellulases, hemicellulases) and lignin-oxidising enzymes (peroxidases, laccases) are important in this respect and may reveal new details of fibre morphology and ultrastructure.

Despite the knowledge resulting from earlier and ongoing research, there still exists a lack of information on the chemistry and structure of wood fibres. Large variations can be found within a single tree, from the pith to the bark and from the base to the top of a tree. Often the chemistry and structure of a wood cell are extremely heterogeneous and difficult to investigate with conventional techniques. Rapid developments in molecular biology, microscopy and spectroscopy have now provided techniques, which will allow the detailed study of the basic building elements of plant fibres as well as the influences of chemical, enzymatic and mechanical treatments. For example, recent studies with antibody labelling have shown that lignin structures vary in different cell wall layers. Moreover, these patterns vary between normal wood and compression or tension wood.

Natural variability is, in general, an obstacle for the industrial use of wood and fibres. For example, the major problems encountered with compression wood relate to the heterogeneity of wood and fibre products and concern both processing and utilization: Drying-induced warp, surface quality and dimensional stability of wood and paper products. Similar problems have been reported in relation to tension wood for a variety of hardwood species. Tension wood, on the other hand, is usually associated with a higher log-end cracking risk following cross-cutting and steaming, and other growth-stress related problems. Several EU sponsored[*] and national projects have highlighted the limited understanding of RW as well as the necessity to combine knowledge of tree physiology, biomechanics, wood science and wood technology to address these problems.

A consideration of secondary metabolites (extractives), although important for some species and practical applications, has been excluded from the scope of this Action devoted to aspects related to the major components, polysaccharides and lignin, regarding wood formation and cell wall properties. RW will be given special attention as it provides a key for the understanding of the structure-properties relationships; it is by nature a quantitative trait and one goal of this Action will be to study the environmental and genetic factors that account for the observed phenotypic variation.

This COST Action is building on the outcomes of expired as well as running Actions of the COST Domain on Forests and Forestry Products (FFP), for instance: completed COST Action E8 "*Mechanical performance of wood and wood products"*; completed COST Action E10 "*Wood properties for industrial use*"; completed COST Action E11 "*Characterization methods for fibres and paper*"; running COST Action E28 *"Genosilva: European Forest Genomics Network"*; completed COST Action E20 "*Wood fibre cell wall structure"*; running COST Action E35 "*Fracture mechanics and micromechanics of wood and wood composites with regard to wood machining*".

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* For instance in FP5: FAIR Project CT-98 3606 "Stresses in beech"; QLRT-2000-00177 project "Compression wood in conifers - the characterisation of its formation and its relevance to timber quality"

COST Action E20 worked out new aspects on the distribution of cell wall components and on the structure of wood cell walls. Building on these anatomical and chemical fundamentals, this Action focuses on the better understanding of the structure and biosynthesis of macromolecules and methods that influence those structures for a more efficient utilisation of wood as well as for the development of new innovative products.

B. Objectives and Benefits

The main objective of the Action is to achieve a better understanding of the structure and biosynthesis of wood macromolecules like lignin, hemicelluloses and cellulose and their impact on wall assembly and wood properties, including reaction wood, for the development of new products based on wood.

The COST Action will aim at the formation process, structure and properties of cell wall and cell wall constituents, with a focus on RWs. The results will be of importance for addressing problems related to variability and RW occurrence at both levels, forest production as well as wood and paper production. The **means** to achieve this objective will be:

- bringing together scientists from a broad background of research on cell-wall macromolecules, wood formation, wood and fibre properties, to exchange their knowledge, techniques and methodologies in a synergistic way;
- finding better methods and tools for the analysis and characterisation of wood fibre cell walls, their native structure and developing new techniques for changing the structure using chemical, mechanical and enzymatic treatments;
- understanding and possibly controlling the assembly of fibre walls and studying the regulation of RW formation by identifying genetic traits involved in the biogenesis pathways;
- compiling and analysing data on the properties of abnormal and normal wood tissues and wood fibres, as well as of related problems at the processing and utilization stages;
- developing basic science on fibre structure, formation and properties necessary for addressing the practical problems related to the fibre wall structure and RW occurrence in the various areas of the whole wood chain, including forestry and tree breeding as well as the wood and paper industries;
- creating a European network on these topics.

The **benefits** from this Action will be:

- An increased knowledge as to how fibre properties at the molecular and ultrastructural may be modified in order to improve processing and quality of pulp, paper, solid wood products and other types of wood-based products;
- Compilation and analysis of comparable information on the variation in fibre properties, resulting in improvements of existing products and the development of new types of wood-based products for the consumer market;
- Improved understanding of biosynthesis and variability of cellulose, hemicelluloses, lignin and the whole wood fibre cell wall;
- Increase of knowledge transfer through Short Term Scientific Missions providing an improvement of qualification for young scientists;
- Promotion of knowledge in European countries on new developments in research on RW and wood macromolecules through workshops and conferences;
- Development of interdisciplinary research activities;

- Promotion of interest in wood science among students and specialists for other materials;
- Maintaining Europe's position at the forefront of knowledge in these fields and thereby retaining the competitiveness of European forest industries;
- Improvement of European co-operation between research groups on wood constituents, structure and properties, and an increase in the exchange of methodologies, ideas, graduate students and researchers between these groups.

Expected **economic and technical benefits**:

- Higher efficiency in the use of timber as raw material resulting from a better understanding of the variation in properties;
- Improved wood and paper processing techniques regarding the treatment of RW, as well as improved forestry techniques, leading to waste reduction and cost reduction within the whole wood chain;
- Optimisation of forest management for growing trees with a higher uniform quality and less occurrence of RW;
- An increase in value of wood products through an improvement of quality (pulp and paper properties, printing properties etc.);
- Finding new fields for the uses of reaction wood materials;
- Higher efficiency of reaction wood detection at the various stages from tree growth to wood processing and paper making;
- Reduction of human risk during log felling (e.g. log splitting) and timber processing (e.g. log movement during sawing) by a better knowledge of reaction wood consequences.

C. Scientific programme

The scientific programme will be based on workshops and on strong networks created by the Working Groups. In addition to workshops and conferences, the exchange of researchers using the Short-Term Scientific Mission scheme will guarantee this transfer. The knowledge transfer itself has the highest priority for the Management Committee (MC) since the Working Groups are connected in a way that data transfer is absolutely necessary; each Working Group (WG) providing relevant information for the others. The scientific programme to achieve the objectives is presented in detail below, in terms of each WG:

WG 1: Biosynthesis and structure of cellulose and polysaccharides

WG 2: Biosynthesis and modification of lignin

WG 3: Formation and induction of reaction wood

WG 4: Relating wood and fibre properties to structure and formation

Scientific programme area 1 (Biosynthesis and structure of cellulose and polysaccharides)

The research will focus on the formation and deposition of the cellulose and hemicelluloses in the cell wall. More investigations are needed on the variation in the orientation of cellulose microfibrils, i.e. the microfibrillar angle (MFA) in the fibre cell wall. The purpose is to further develop techniques for measuring MFA, like X-ray diffraction and synchrotron radiation. The genetic and environmental control of the orientation of microfibrils is also an important aspect to be studied.

The chemistry of polyoses (hemicelluloses) and interaction between different macromolecules in the cell wall will be investigated and discussed in this group. In cooperation with WG3 and WG4, RWs representing extreme cases of cell wall organisation will be given special attention, especially the gelatinous fibres of tension wood characterised by very high cellulosic content.

Scientific programme area 2 (Biosynthesis and modification of lignin)

The research will focus on biosynthesis and lignin structure. Intensive research is being conducted on the final steps of lignification and characterisation of lignin in different cell wall layers. Furthermore, the effect of wood modification (high temperature drying, UV-treatment, micro-wave treatment, precursor impregnation) on lignin structure and properties of solid wood and wood fibres will be investigated. New techniques are under development for lignin analyses (Fast Transform Infra Red Technique (FTIR), antibody labelling). The natural variation in the structure and content of lignin needs to be analysed in order to find specific trees for selective breeding. Possibilities of genetic engineering of lignin structures will be investigated and discussed in this group. It will also address the role of cell-wall maturation and lignification in the process of growth stress generation, in relation with WG1 and WG3.

Scientific programme area 3 (Formation and induction of reaction wood)

The third Working Group will study the induction and formation process of RW, either under natural growth conditions or provoked artificially in growing trees. The occurrence of RW in the stem of a tree is essentially dependent on various growth factors, as it is produced by the plant as a result of external stimuli. However, the nature of reaction to these stimuli differs according to the genotype, resulting in a variety of RW types among wood species. Therefore the identification of genetic factors involved in the biogenesis pathways is required to understand the formation and regulation of RW. The effect of genetic manipulations on RW production, either through traditional tree selection techniques or the use of transgenic material, needs to be considered. The evolutionary aspect behind the two main strategies developed by conifers (compression wood) and angiosperms (tension wood) should be addressed. On the other hand, the stimuli controlling RW formation should be studied in connection with practical issues at the forestry level but also integrated into a general biomechanical approach relating the mechanical function of RW to biochemical processes involved in wood formation. The scientists participating in this Working Group will be foresters involved in tree selection and tree breeding, biologists working on the genetics and biogenesis of RW, physiology, eco-physiology and architecture of trees, as well as engineers studying and modelling the structural mechanics of cells and trees, or the information flow within plants. In fact, rather than actually solving all the scientific problems associated with RW formation, which would be a large programme in itself, this WG will combine existing knowledge and stimulate related research, through the promotion of cooperation between these very different disciplines. Therefore the interdisciplinary approach required in the whole area is particularly relevant for this WG.

Scientific programme area 4 (Relating wood and fibre properties to structure and formation)

The properties of RW differ anatomically, physically, mechanically and chemically from normal wood. The observed extent of differences varies among species. Therefore, typologies beyond the conventional definition of compression and tension wood will be elaborated. This fourth WG provides the link between all preceding WGs by addressing some aspects of the structure-properties relationship in wood and paper, with special focus given to the extreme cases represented by RW, without neglecting other sources of variation such as juvenile wood. Furthermore, the WG will work on the experimental characterisation of all types of unusual tissues at various scales, and the development of mechanical models attempting to explain the differences. For instance, characterisation of cell wall properties through micromechanical testing, finite element analysis

(FEA), mechanical event simulation (MES), micro-macro and homogenisation approaches will be encouraged. Although devoted to basic aspects of material properties, this WG addresses the practical concerns of the wood and paper industries, by developing the background knowledge necessary to address problems related to natural variability and RW occurrence. Therefore it is expected that scientists involved in these two sectors will participate actively in this WG.

Links between Working Groups

WG1 and WG2 are naturally linked to each other because they both deal with the characterisation of the main cell-wall constituents, which cannot be completely separated. WG3 exchanges with WG1 and WG2 because the cell growth stress generation is a mechanical consequence of cell-wall formation and RW influences the production of macromolecules. WG4 will benefit from WG1 giving insights into cell-wall organisation; from WG2 because of the relation between the lignification process and growth stress generation; and from WG3 explaining the process of material elaboration. In return, it will stimulate the work on cell-wall composition and wood formation, developed in WGs 1, 2 and 3. In addition, possible links of WG4 of this Action with WG1 "Microstructure and Micromechanics" of running COST Action E35 *"Fracture mechanics and micromechanics of wood and wood composites with regard to wood machining"* will be considered.

Instruments and methods to be used in the COST Action:

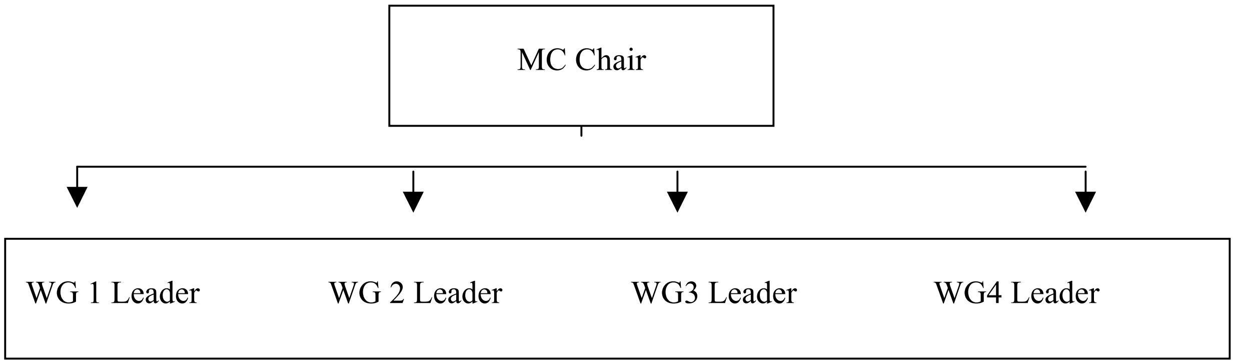
- Growth and stress assessment on standing trees
- 3D digitising, kinematics and biomechanical analysis of stem shape
- Preparation and micro-preparation equipment
- All appropriate microscopic methods for observing behaviour and structure
- Quantitative anatomy and image analysis
- All appropriate spectroscopic methods
- X-ray and Laser scanning and diffraction
- Biochemistry, immunocytochemistry and autoradiography
- Nuclear magnetic resonance
- Facilities for conventional mechanical and physical characterisation
- Equipment for micromechanical testing, e.g. micro-balance and laser micrometers
- Workstations for numerical simulations, e.g. Finite Element Analysis (FEA) and Mechanical Event Simulation (MES)

D. Organisation

The COST Action will be led by a Management Committee (MC). Responsibility for detailed planning, execution and documentation of the individual activities will be delegated by the MC to a Steering Group (SG), consisting of the Chair of the COST Action, the Working Group Leaders, and when necessary others through appointment by the MC. Where possible, the MC or SG meetings will be organised in connection with Working Group meetings, workshops and conferences to minimise the costs involved in the coordination of the COST Action.

One meeting per year will be organised in form of a Scientific Workshop/Conference.

Experts from industry will be invited to participate actively or to join the workshops in order to exchange ideas and to contribute to the dissemination of the results.



The work of this COST Action will be carried out by the four Working Groups described in Section C:

WG 1: Biosynthesis and structure of cellulose and polysaccharides

WG 2: Biosynthesis and modification of lignin

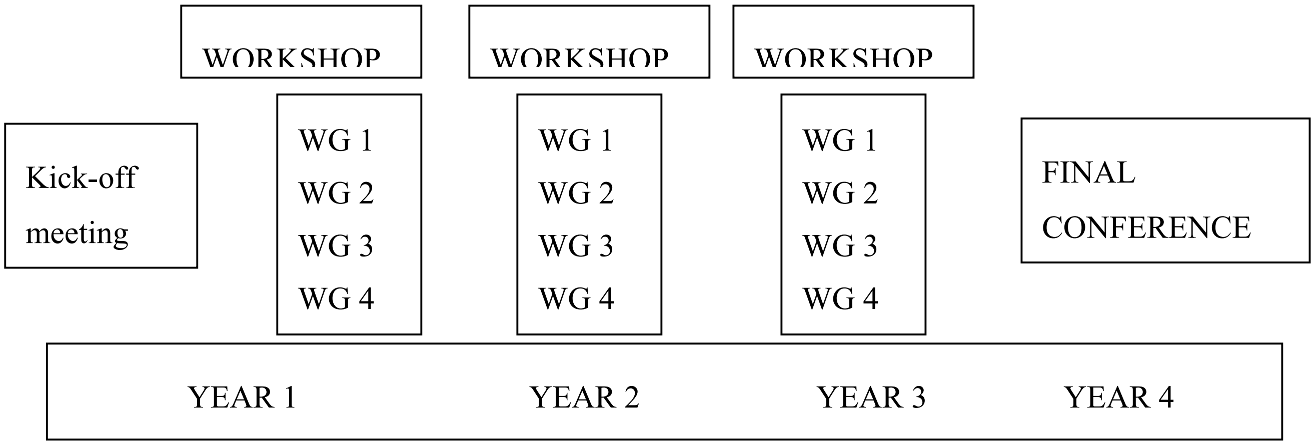
WG 3: Formation and induction of reaction wood

WG 4: Relating wood and fibre properties to structure and formation

Strong links between the four Working Groups will be created and maintained, since all aspects are important in order to understand the chemistry and structure of cell wall and RW and possibilities to modify them.

E. Timetable

The duration of the Action is four years and the time schedule for various activities is shown in the following chart:


WORKSHOP
WORKSHOP
WORKSHOP
Kick-off meeting
WG 1
WG 2
WG 3
WG 4
WG 1
WG 2
WG 3
WG 4
WG 1
WG 2
WG 3
WG 4
FINAL CONFERENCE
YEAR 1
YEAR 2
YEAR 3
YEAR 4

F. Economic dimension

The following COST countries have actively participated in the preparation of the Action or otherwise indicated their interest:

- Austria
- Belgium
- Finland
- France
- Germany
- Netherlands
- Italy
- Poland
- Slovenia
- Sweden
- Switzerland
- United Kingdom

On the basis of national estimates provided by representatives of these countries, the economic dimension of the activities to be carried out in those countries has been estimated, in 2004 prices, at roughly Euro 16 million.

This estimate is valid under the assumption that all the countries mentioned above participate in the Action. Any departure from this will change the total cost accordingly.

G. Dissemination

The Management Committee will set up effective dissemination mechanisms to publish the objectives and the progress of the COST Action in order to inform a wider scientific community and the public. The Management Committee will ensure the organisation of meetings of the Working Groups and Conferences. During the Workshops, detailed plans will be formulated and activities agreed upon for the main scientific and technical areas for which each Working Group will be asked to report at the following conference. Workshop and Conference proceedings will be prepared and will be made available electronically on the Action Homepage and as a hardcopy.

A web-based Internet platform will be used as an effective dissemination tool. A Web-Coordinator (member of the Management Committee) will provide a uniform frame, maintain the network as well as control the flow of the dissemination of results and the news of events and meetings.

The main homepage of the Action and the specific Working Groups' homepages, with necessary links, will reflect the integrating character of the cooperation. They provide the COST Action with the platform needed to be perceived and classified as a unifying focus point across the European scientific community. Participants of the Action are expected to publish results in appropriate scientific and technical journals.

The COST Programme and its financial support will be acknowledged in any kind of specific or general dissemination activity.
