# Delamination in Wood, Wood Products and Wood-Based Composites

Voichita Bucur
Editor

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Springer

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*Cover image*: Intra-ring internal checking in sample (100 × 50 mm – width × thick) of regrowth Victorian Ash (*Eucalyptus delegatensis* or *E. regnans*). Photo taken by Philip Blakemore.

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# Foreword

It is with great pleasure that I prepare this foreword. The senior author, Professor *Voichita Bucur*, is one the preeminent wood scientists in the world today. She is well known for her excellent research on acoustics, especially the acoustic properties of wood and wood-based materials. Her previous books *Acoustics of Wood* and *Nondestructive Characterization and Imaging of Wood* are outstanding reference documents; they provide a summary of much of the world's research and development efforts in these two important technical areas.

Professor Bucur has contacted widely respected technical authorities and asked them to prepare chapters dealing with various aspects of the formation and detection of separations and delaminations in wood-based materials.

*P. Blackmore* – CSIRO Australia, *S Blumer* Holzinnovationzentrum, Austria, *G Daian* Melbourne University, Australia, *BSW Dawson* – SCION New Zealand, *F Divos* – Faculty of Wood Science Sopron, Hungary , *L. Donaldson* – SCION New Zealand, *T. Gereke* ETH Zürich, Switzerland, *P.J. Gustafsson* Lund University Sweden, *N. Haque* – CSIRO Australia, *CL Huang* – Weyerhauser USA, *S. Kazemi-Najafi* – Tarbiat Modares University, Iran, *C. Mueller* – ETH Zürich, Switzerland, *J. Neuenschwander* – Empa Switzerland, *P. Niemz* – ETH Zürich, Switzerland, *K. Persson* – Lund University Sweden, *M.S.J. Sanabria* Empa, Switzerland, *U. Sennhauser* Empa, Switzerland, *A. P. Singh* – SCION New Zealand, all graciously agreed and provided excellent technical contributions.

This book is organized into three parts. Part I, General Aspects, presents much needed basic information, including terminology, the theoretical basis for evaluation of delamination in wood and wood-based materials, and mechanical stress development in the woody cell wall in response to various stressors. A vibration-based approach is proposed to evaluate delamination with ultrasonics or with low frequency vibrations. Crack initiation and growth of delamination is studied with a fracture mechanics approach. A theoretical model for collapse recovery is proposed.

Part II, Methodology for Delamination Detection and Factors Inducing and Affecting Delamination, begins by examining a variety of methods for detecting delamination in wood products, then delves into discussion of the formation of delamination or separations at several levels – from the microscopic, anatomical level within solid wood sections to examination of the interface of wood and surface coatings. The techniques presented for observing separations include confocal laser scanning microscopy, light microscopy, scanning electron microscopy and ultrasonics. Excellent discussions of delamination caused by moisture induced stresses, including those that form during the drying of wood and lumber products and those observed with weathered wood surfaces, are included.

Part III, Delamination in Different Products, focuses on practical aspects of delamination in a wide range of wood products. An excellent discussion of the industry's perspective is presented. Practical discussions dealing with the formation, detection, and performance problems associated with delamination in trees, logs, laminated panels, composites, glued laminated timbers, and parquet floors are presented in detail.

The authors prepared this book to serve as a primary reference on subject of delamination in wood-based materials and products. It was prepared to provide a concise source of information on the topic to manufacturers and users of wood products, as well as research scientists. It was made possible through the efforts of dedicated scientists who spent countless hours in laboratories developing technical information on this important subject. This book is a tribute to their efforts and a significant contribution.

This book is a significant contribution to the wood science and technology literature. Professor Bucur has completed another significant contribution to the wood science literature.

Project Leader Robert J. Ross, Ph.D.
USDA Forest Products Laboratory
October, 2009

# Preface

Delamination occurs in all man made composite materials as well as in natural composites like wood, bones or rocks. Many groups of specialists with widely different backgrounds and interests need knowledge of factors influencing delamination in wood, wood products and wood based composites. I was amazed with the lack of information on the subject and particularly with the way in which the available information is scattered in the literature. Out of this amazement arose the idea to write and edit this book.

Part I of the volume deals with general aspects of delamination, the terms used for defining delamination in wood science and technology and with the theoretical aspects in the evaluation of delamination. Part II is directed at the methodology developed for delamination detection. Factors that induce and affect delamination are analyzed. Part III is a study of delamination in different products. Extensive reference is made to the literature. An attempt has been made to select the most important references for the corresponding chapter. Thus, for any given topic, it should be easy for the reader to quickly acquaint himself with what has been done by looking up the listed references. It is also the hope of the authors that this volume will be a valuable source of information for the practitioner who mostly deal with the design or evaluation of structures subjected to delamination.

In recent years manufacturers are becoming more aware of the importance of delamination and other factors that affect the performance of their finished products. Thus there is an evident need for this type of book.

Experts called upon to render opinions on structure safety are faced with not only the daunting task of discovering and quantifying structural defects such as delamination, but also translating those observations into the probability of failure and determining levels of “unacceptable risk”. Even though the mechanics of wood failure is better understood today than two decades ago, and the tools for nondestructive identification of defects are more accurate and powerful, the fact remains that deciding what level of defect represent an “unacceptable risk” continues to be a subjective judgment. This is particularly true for structures with significant but not severe defects such as delamination and on sites that present high levels of risk (i.e. snow).

The bibliography of this book is intended to be comprehensive and we hope, an important contribution of this book (near 1000 references) is to accurately identify the evolution of ideas in the last decades. All references cited in the text are included in the reference section at the end of each chapter.

At present, no comparable book exists covering the entire field of delamination in wood, wood products and wood based composites.

The editor would like to firstly acknowledge the contributions by colleagues acting as authors of the individual chapters, who gave their time and energy to prepare this excellent text.

I would like to express my sincere thanks to all colleagues and organizations that have made possible the publication of this volume, to the CSIRO – Commonwealth Scientific and Industrial Research Organisation – Australia and SCION- Forest Research Institute, New Zealand, who supported this idea. In preparing such a text it is very difficult to acknowledge all the help given to the editor. I am indebted to the three main scientific communities, *wood science, mechanical and acoustical* communities who have undertaken research and development that is reflected in the cited publications. This book encompasses a variety of recent research result, a number of unpublished results and refinement of older material.

This book would certainly not have been possible without the help of my colleague *Nick Ebdon*, CSIRO – Clayton, who work very hard on the preparation and formatting all figures.

Last but not least, I would also thank my family and my Australian friends who followed with interest and enthusiasm the progress of the manuscript of this book.

Working for this book was for me an extraordinary opportunity to discover the natural splendors of Australia and the atmosphere of this country, which is a proud modern civilization.

Melbourne, Victoria
October 2009

Voichita Bucur

# Acknowledgements

Permission for the figures cited in this book have been granted by Copyright Clearance Center, (http://www.copyright.com), by different organisations and colleagues cited in the corresponding chapters of this book. The authors are very thankful for their kind permission to reproduce figures.

As editor of this book, I own special thanks to ***Ms Danila Durante***, Information Specialist, CSIRO Australia, Information Management & Technology Division, in Melbourne for numerous hours spent together for copyright permissions with the new electronic system required by Copyright Clearance Center. Many, many thanks are also addressed to ***Ms Bee Thia***, Information Specialist, CSIRO Australia, Information Management & Technology Division, for her continuous and enthusiastic help in collecting documents and books cited in this volume.

Melbourne, Australia Voichita Bucur

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# Part I
# General Aspects

# Chapter 1
# Introduction

**Voichita Bucur**

## Contents



## 1.1 Background

In order to improve the quality of mass produced wood-based composites and in order to undertake quality assessment of adhesive interfaces in these materials it is first necessary to develop the theoretical basis describing both qualitatively and quantitatively, the quality parameters of the composite, and secondly to develop new non-destructive techniques for their testing and evaluation.

Mechanical integrity of interfaces in wood-based composites plays a major role in determining the serviceability of structures and their components. New advanced materials (i.e. parallel-strand lumber, laminated veneer lumber, etc.) are designed with specialty interfaces to increase fracture resistance of wood-based composite materials and to accommodate residual stresses. Of particular note is that the mechanical properties of wood-based composites, used mainly in civil engineering, may degrade severely in the presence of damage, often with tragic consequences. Therefore damage detection is a very important issue in the context of structural health monitoring for mechanical engineering infrastructure with elements in wood and wood-based composites.

Wood-based composites are complex materials exhibiting important anisotropic properties. Commonly observed damage in these materials are: delamination

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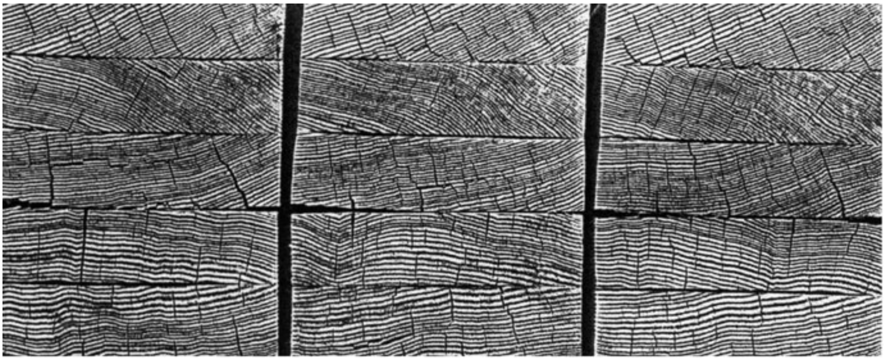

**Fig. 1.1** Delamination observed on cross sections of Douglas-fir laminated lumber. Note delamination occurs predominantly in wood elements in the direction of medulary rays, frequently starting or finishing at the interface between the earlywood and latewood (Vick and Okkonen 2000, Figure 5a)

between plies, debonding of wood–adhesive layers, or wood fibre fracture. Delamination, which is a debonding of two adjoining layers in the laminated wood-based composite, is probably the most frequently observed damage.

Delamination can occur at several scales: Fig. 1.1 shows the cross section of Douglas – fir lumber laminates with macroscopic delamination, while at a submicroscopic scale, delamination can be observed between the $S_1$ and $S_2$ layers in spruce latewood tracheids, as can be seen in Fig. 1.2.

Delamination may result from manufacturing errors, by imperfect bonding, by separation of adjoining piles, etc., or, during in service loading such as by accidentally excessive loading produced for example by snow or, by fatigue in cyclical environmental conditions of temperature and humidity.

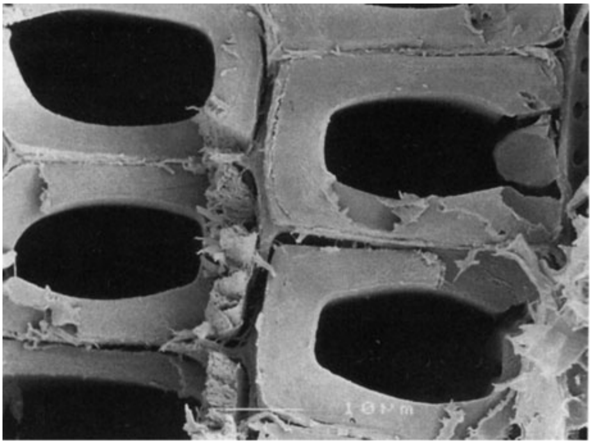

**Fig. 1.2** Delamination in spruce latewood tracheids between $S_1$ and $S_2$ layers (Zimmermann et al. 1994, Figure 3)

As noted by Garg (1988) many years ago, the prediction of delamination in composites is a challenge for both scientists and manufacturers. This is due to the large number of parameters involved in the design of composites and, on the other hand, to the complexity of the stress state which leads to the initiation and propagation of delamination.

For the initiation aspect of delamination, the tolerance prediction is based on semi-empirical criteria, such as point-stress or average stress criteria. Due to the use of such criteria, industries are led performing numerous tests in order to ensure the safety margins for delamination failure are not exceeded. The non-propagation certification relies on fracture mechanics analyses, which are very complex and introduce difficulties for the characterization of the initial delamination pattern (Srinivasan 1996; Murata and Masuda 2006).

The last 30 years there have been several important advances toward a better understanding of the mechanics of laminated composites and of the damage mechanisms, because of their intensive utilisation in aerospace engineering. This progress concerns the analysis and identification on the micro, macro and meso scales, as well as the development of advanced anisotropic material models. To be able to rely on computational models, both academics and manufacturers recognize that a prerequisite is to develop a detailed material model with a clear identification procedure and to validate this model by means of representative experimental tests.

The physics of delamination is governed by interactions among different damage mechanisms, such as fibre breakage, transverse microcracking and debonding of the adjacent layers of the cell wall. To understand the physics of delamination in composite biological materials and more specifically in wood, wood based products and wood-based composites, it is necessary to have detailed knowledge about the microstructure of these materials.

As noted by Kelly (1989) in the Concise Encyclopedia of Composite Materials, "plant cells are a good example of laminated composite material; the shape of the cells is roughly tubular with various laminae of cellulose microfibrils glued together to form a wall. Each lamina has a characteristic fibre orientation which can be random, cross-helical or single-helical. . . . . . These biomaterials are grown under stress; this means that the loading conditions of the structure as a whole can be used effectively as blueprints for the most efficient use of fibre reinforcement. By their very nature, natural fibrous composites are better materials in tension than in compression and their use in many applications is often limited by this fact. The excess of tensile strength available can be profitably used to pre-stress in tension the regions of the structure which are more vulnerable into compressive loads. Also the presence of water as compression members will result in lighter structures".

## 1.2 Solid Wood

Wood is a natural fibrous, layered composite which exhibits a remarkable combination of properties related to strength, stiffness and toughness (Vincent and Currey 1980; Schniewind 1989). As noted by Schniewind (1981) "wood is composed from a complex aggregation of cells, of tubes shape, which during the life of the tree had biological function. The structural features of wood are oriented following the principal directions of growth of the tree, namely longitudinal-parallel to the axis of the tree, radial and tangential – versus the annual rings"

Several models have been proposed to represent wood structure in relation to its mechanical behaviour, starting with Price (1929), who modelled the cell structure as an array of parallel cylindrical tubes, of isotropic structure, oriented in the stem direction.

Another version, proposing also a tubular model, useful for modelling the cell wall as a laminated composite material is presented in Fig. 1.3. A softwood or conifer wood cell is essentially a hollow tube of about 30 μm diameter with a multi layered laminated wall composed generally from four layers – primary wall, $S_1$, $S_2$ and $S_3$. The $S_2$ layer, is the principal load bearing component of the cell wall and is close to 80% of the total cell wall area. It contains cellulose components in the form of microfibrils of about 10–20 nm in diameter. In most cases the microfibrils lie at an angle to the cell axis and form a steep helix at an angle, ranging between 0° and 25° and 0° and 50° for hardwood and softwood respectively. Fibres with low microfibril angle (10°) posse high tensile strength (400 MPa) and low elongation (1%). The cells are parallel to the grain direction and are bonded to each other by an amorphous matrix containing mostly lignin. Nearly 90% of the cells are aligned in one direction forming a honeycomb structure with highly anisotropic mechanical properties. The alternation of spring and summer growth (earlywood and latewood layers in the annual ring) in softwood and ring porous hardwood species from temperate climates produces well known ring patterns which introduce a further element of complexity.

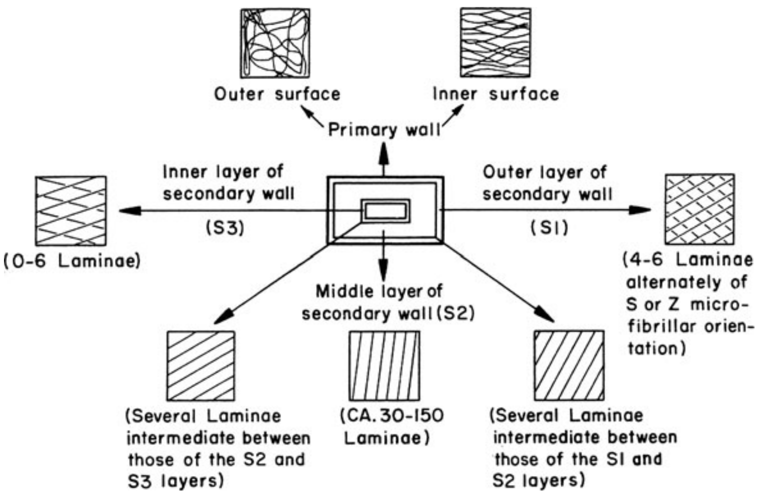


**Fig. 1.3** Layered structure of the cell wall modelled as a laminated composite material (Mark 1967, Figure 1-7)

A more complex model was proposed by Mark (1981), and consists of a matrix and framework. The corresponding mechanical properties of the cell wall material can be derived from the natural polymer constituent (cellulose, hemicellulose and lignin) properties by the rule of mixture. The stiffness and strength of cellulose itself are considerable, the theoretical value for Young's modulus and tensile strength being in the order of 250 GPa and 25 GPa (Mark 1967) respectively.

Wood mechanical properties are considerably inferior to those of pure cellulose. Figure 1.4 shows the degradation of Young's modulus from cellulose to wood. To illustrate this aspect, the ratio $\frac{E}{\sigma_{\text{rupture}}}$ was analysed for several situations and the smaller the ratio, the better the material will be in resisting crack propagation. In an ideal solid this ratio is in the order of 10, however this ratio is about 100 in longitudinal anisotropic direction of wood. The reduction of the Young's modulus $E$ from cellulose to wood is due to largely to the very complex structural arrangement of this material in which the microfibrillar angle plays a very important role.

The development of computation techniques in the last 25 years, and the progress achieved in mechanical characterisation of solids in general and of composite materials in particular, affected positively the development of modelling of the wood structure.

Gibson and Ashby (1988) proposed a cellular structure model with hexagonal cell shape and used for calculation the principles of cellular solid mechanics. Some improvements of this approach were given by Kahle and Woodhouse (1994) and Watanabe et al. (2000, 2002), which considered the cell wall material as transversely isotropic.

Significant progress in Wood Science has been achieved using multiscale models which were elaborated by using three-dimensional finite element simulation of representative softwood related cellular models. In addition data related to the microstructural characteristics such as the micrifibril angle and the chemical composition of the cell wall such as lignin, hemicelluloses, water and crystalline cellulose were also integrated into their models (Harrington et al. 1998; Astley et al. 1998; Yamamoto 1999; Persson 2000; Watanabe and Norimoto 2000; Yamamoto et al. 2005; Hofstetter et al. 2005, 2006; Fritsch and Hellmich 2007).

Using the experimental observations of wood behaviour at different scales, Hofstetter et al. (2007) proposed a very original approach considering simultaneously the continuum mechanics for the solid-type behaviour of the cell wall and on the other hand, the unit cell method, for the plate-type behaviour of the softwood microstructure. It was stated that the activation of different load-carrying mechanisms of cellular structure depends on the loading state of wood, such as for example:

- the plate-type bending and shear deformations of the cell walls which are dominant in tangential direction, when the transverse shear loading and longitudinal compression straining are applied on solid wood specimens.
- the solid-type deformations are dominant in longitudinal and radial directions when longitudinal shearing loading straining are induced on wood specimens.

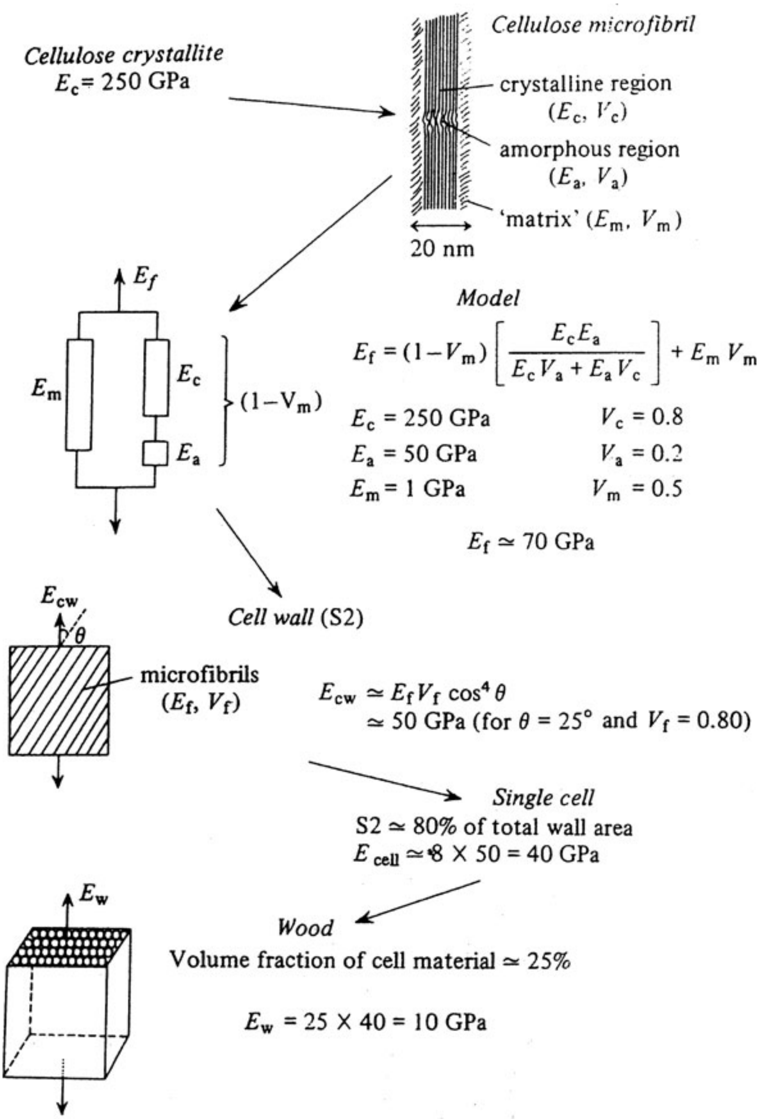


**Fig. 1.4** Schematic representation of the degradation of mechanical properties of wood (expressed by Young's modulus) compared to those of pure cellulose (Jeronimidis 1980, Figure 2)

At a cellular scale the plate-like deformation modes were studied combining random/periodic multi-step homogenisation with corresponding values obtained from continuum micromechanics modeling. The average predictive capacity of this model is low, about 8%, with very large variations depending on the value of the elastic constants. The highest errors were observed on $G_{RT}$(error can be as high as 290%) and on Poisson's ratios (error of about 75%). It is very likely that the predictive capacity of this model could be substantially improved by using more accurate values of the elastic constants at a microscopic scale, which can be obtained with the development of specific acoustic microscopic technique as suggested by Bucur (2003).

All these studies related to the modelling of wood structure clearly suggest that delamination can occur between different layers at submicroscopic, microscopic and macroscopic structural levels.

## 1.3 Wood-Based Composites

With regards to the wood-based composites, the mechanical behaviour of two groups of products must be analysed: the laminated wood products such as glulam, plywood, laminated veneer lumber (LVL), parallel-strand timber (PSL), structural particleboard, oriented strandboard (OSB), the fibre-based products such as fibreboard particleboard, paper and fiber reinforced composite such as fibre-cement boards, carbon fibre-reinforced plywood, and wood and glass-fibre composites, paper, etc.

Performance criteria for wood-based composites relate directly to product end use. Laminated products are frequently used for structural purposes. This requires consideration of engineering strength needs, safety and short and long term response of the material to the service environment. Structural, exterior-grade products have the most demanding bond-quality requirements, since glue line failure could be catastrophic to these structures. In these situations glue line strength, durability and reliability must be assured, by computational analysis and bond quality testing programs. Computational models to simulate mechanical behaviour of new wood-based composites are critically needed because of cost-effectiveness. The effects of varying raw material characteristics on the mechanical properties of prospective new products can be thoroughly analysed. The intensive and expensive bond quality testing programs also can be improved by modeling.

The factors affecting the quality of adhesion in wood-based composites are related to the heterogeneous and anisotropic character of wood reflected in the anatomical characteristics, permeability, density and moisture content, fibre bonding sites, and on the other hand in the nature of adhesives (thermosetting or thermoplastic). As noted by Schniewind (1981) "bond formation depends upon the development of physical and chemical interactions both within the bulk adhesive polymer and at the interface between adhesive and wood. Interactions within the adhesive accumulate to give cohesive strength while the forces between adhesive and wood provide adhesive strength. Both should exceed the strength of the wood allowing substantial wood failure during destructive testing of high-quality bond". Optimum bond formation requires intimate contact between adhesive and wood substrates to ensure macromolecular interaction over a large area. Different techniques (X-ray, NMR, microindentation, etc.) were developed for the mechanical characterisation of the wood-adhesive interface. Figure 1.5 shows the light microscopy image of a spruce parallel-strand lumber specimen which contains fractured

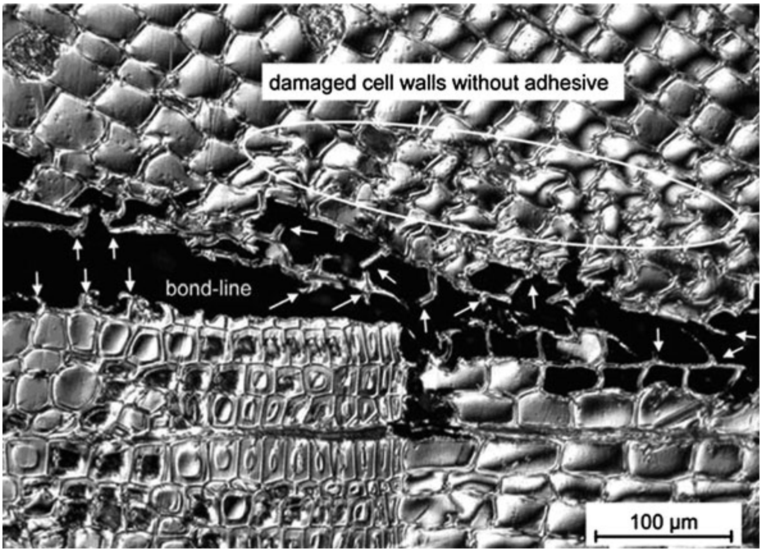


**Fig. 1.5** Transverse section of spruce parallel-strand lumber which contains fractured and delaminated zones. The arrows indicate the zones tested via nanoindentation (Konnerth and Gindl 2006, Figure 1)

and delaminated zones tested with the nanoindentation technique developed by Konnerth and Gindl (2006).

Modelling of the mechanical behaviour of laminated wood composites for predicting elasticity and strength has been reported for more than 30 years in numerous articles. A small snapshot of these include: Hunt and Suddarth (1974) who predicted the Young's modulus and the shear modulus of medium-density flakeboard, Okuma (1976) studied the plywood properties influenced by the glue line, Gerrard (1987) proposed an equivalent orthotropic elastic model for the properties of plywood, Shaler and Blakenhorn (1990), Wang and Lam (1998) or Lee and Wu (2003) predicted the mechanical properties of oriented flakeboard. The mechanical behaviour of laminated veneer lumber, LVL, has been studied by Bejo and Lang (2004), Castro and Paganini (2003), Hata et al. (2001), Kamala et al. (1999), Lang et al. (2003), Park and Fushitani (2006).

Finite element modelling of laminated wood composites as a multilayer system was proposed by several authors (Triche and Hunt 1993; Suo and Bowyer 1995; Clouston et al. 1998; Morlier and Valentin 1999; Nafa and Araar 2003; Wu et al. 2004) for predicting tensile, compression or bending strength and stiffness using failure criteria. Clouston and Lam (2001, 2002) and Clouston (2007) proposed an advanced methodology for analysing the multiaxial stress states in small specimens of parallel wood-strand composites, using a 3D non-linear stochastic finite element model and Monte Carlo simulations. The Tsai-Wu strength theory to predict the ultimate load carrying capacity of a centre point off-axis bending member made from Douglas fir laminated veneer, incorporating the size effect was reported by Clouston et al. (1998).

The behaviour of wood cement composites has been reported from the beginning of there presence on the market, over 70 years ago as low-density and insulation material. Today the cement bonded structural flakeboards offer high, fire, insect and fungal resistance. In addition the quality has improved resulting in better weatherability and acoustic insulation (Lee et al. 1987; Mosemi and Pfister 1987; Fan et al. 1999).

References relating to the modelling of mechanical behaviour of fibre-based composites are as abundant as those for laminated wood-based composites, but only several are cited here (Smulski and Ifju 1987; Claisse and Davis 1998; Lopez-Anido et al. 2000; Moulin et al. 1990; Ogawa 2000; Pirvu et al. 2004; Rowlands et al. 1986; Tascioglu et al. 2003; Tsai et al. 2005; Xu 2002; Xu et al. 2005; Chakraborty et al. 2006). Mechanical properties of fibre-based composites are influenced by factors such as: fibre geometry, orientation and distribution, fibres packing in flake of different orientation, random distribution of flakes, moisture content, adhesive-type, etc. Single layer flake models and multilayer mat structures were suggested (Bodig and Jayne 1982; Steiner and Dai 1993; Dai and Steiner1994; Lenth and Kamke 1996) to explain the mechanical behaviour of fibre based composites. Several authors (Ogawa 2000; Tascioglu et al. 2003) reported successful utilisation of hybrid fiber-reinforced polymer composites – glulam products for structural applications in civil infrastructures such as beams for bridges stringers, panels for bridge and pier decks. It was noted that these composites are very resistant to delamination tests during accelerated exposure to wetting and drying (Pirvu et al. 2004)

Mechanical defibering action produces important structural modifications such as: internal fibrillation observed as a helical wraps of fibres, cell wall delamination, external fibrillation which is the peeling off of the fibrils from the fibre surface, with formation of fines, fibrils or fibrillar lamellae attached to the exterior fibre surface and fibre shortening, depending on the refining conditions, the fibre type – hardwood or softwood – and the pulp type – mechanical or chemical. It is appropriate to mention here that the hydroxyl groups available on the surface of the cellulose molecule are the prime means by which fibres and cement, or other material used as matrix, bond together.

The increasing environmental concern about the wastes from wood, wood products, forest waste and construction waste materials has given rise to the development of new or improved technological processes such as the water vapour explosion process. This process rapidly defibrates wood wastes producing a new raw material for novel wood cement composites (Wei et al. 2004). Figure 1.6 shows the interfacial zone between cement and wood fibres, with a delamination of the cell wall near the wood-cement interface.

As noted by Schneider (1994) the development of fibre-based composites testing methodology was encouraged as part of the efforts being made to control the performance of low cost building materials for use in developing countries.

The renewed interest in producing new composites with wood fibre began almost inadvertently in 1960, and Australia was a leading country in this field as noted by Coutts (2005). In the 21st century a great *need* still remains to improve the durability of fibre-based products and to study new, cheaper methods of fibre production and

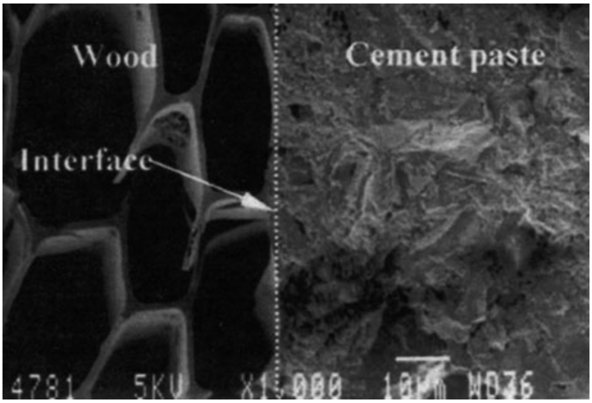


**Fig. 1.6** Interface zone between cement and wood fibres, with delamination of the cell wall near the interface wood-cement. (Wei et al. 2004, Figure 1C)

low cost processes. Durability of these products is related to matrix formulations, processing methods and curing regimes. If natural fibre reinforced cement products are to be readily available for low cost housing much research still remains to be conducted for improving the durability of the products.

## 1.4 Summary

Commonly observed damage in wood products and wood-based composites are: wood fibre fracture, delamination between plies or debonding of wood–adhesive layers. Delamination which is probably the most frequently observed damage, may be produced during manufacturing or, during in service loading such as accidental excessive loading produced for example by snow or, by fatigue in highly variable environmental conditions of temperature and humidity. Damage detection in general and delamination in particular is a very important issue in the context of structural health monitoring for mechanical engineering infrastructure with elements in wood and wood-based composites. The development of computational techniques in the last 25 years, and the progress achieved in mechanical characterisation of solids in general and of composites in particular, affected positively the development of the modelling of wood mechanical behaviour in function of its structure. Related studies clearly suggest that delamination in solid wood can occur between different layers of the cell wall at submicroscopic, microscopic and macroscopic structural levels.With respect to wood-based composites, the behaviour of two groups of products has been analysed: the laminated products (plywood, laminated veneer lumber, parallel-strand timber, structural particleboard, oriented strandboard, etc.) and the fibre-based products (fibreboards, fibres-cement composites, carbon fibre-reinforced plywood, particleboard, wood and glass-fibre composites). Finite element modelling of laminated wood composites as a multilayer system was proposed. More recently analysis of the multiaxial stress states in parallel wood-strand composites, has been proposed using a 3D non-linear stochastic finite element model and Monte Carlo simulations. The development of fibre-based composites testing methodologies must be encouraged as part of the efforts being made to control the performance of low cost building materials.

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# Chapter 2
# Terms for Delamination in Wood Science and Technology

**Voichita Bucur**

## Contents



## 2.1 General Terms

In Material Science, delamination is defined as a sub critical damage to the interfaces between the plies in a laminate composite that causes a reduction in the load carrying capacity of composite (Morris 1992).

The terms which describe delamination in wood and wood- based composites are very numerous and often confusing due to a multitude of reasons (the use of terms which were considered inappropriate in recent days, new technologies related to microscopic observation of the structure, etc). A comprehensive understanding of these terms is essential for the uses of wood products under competitive conditions of modern technology. This chapter discusses the terms that refer to delamination in solid wood, in wood cell wall, in laminated products, and in fibrous and particle board wood-based composites.

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## 2.2 Terms for Delamination in Solid Wood

Terms which express delamination in solid wood have been defined in very well known reference textbooks (Kollmann and Cote 1968; Panshin and de Zeeuw 1980) and standards under the label of defects which develop in wood after it has been cut.

In what follows we quoted the terms as referred in ASTM D9

- *Check* – a separation of wood along the fibre direction that usually extends across the rings of annual growth, commonly resulting from stress set up in wood during seasoning.
  - End check – a seasoning check occurring on the end of a board or other piece of wood.
  - Heart check – a check that extends across the growth layers in one or more directions from the pith toward, but not to, the surface of a piece of wood. A synonym is pith check
  - Roller check – a crack in the wood structure caused by a piece of cupped lumber being flattened between machine rollers
  - Star check – a heart check in which the separation extends in more than one direction from the pith
  - Surface check – a check occurring on the surface of a piece of wood, usually on the tangential face not extending through the piece.
  - Through check – a check that extends through a piece of wood, or from a surface to the opposite or to an adjoining surface.
- *Collapse* – the flattening of single cells or rows of cells during drying or pressure treatment of wood, characterized by a caved or corrugated appearance
- *Cracks* see shake
- *Cross Break* – a separation of the wood cells across the grain. Such breaks may be due to the internal stress resulting from unequal longitudinal shrinkage or external forces.
- *Honeycombing* – in lumber and other wood products, is the separation of the fibers in the interior of the piece, usually along the rays. The failures often are not visible on the surface, although they can be the extensions of surface and end checks.
- *Shake* – a longitudinal separation of the wood. Generally two forms of shake are recognized, although variations and combinations may be used in industrial definitions
  - Heart shake – a shake that starts out at or near the pith and extends radially. Synonyms are heart cracks, rift crack. A heart shake in which several radial cracks are presented is termed a star shake
  - Ring shake – shake occurring in standing trees, in the plane of the growth rings in the outer position of the latewood for partial or entire encirclement

of the pith, occasionally moving radially to an adjacent latewood ring. A synonym is "cup shake". Meyer and Leney (1968) described ring shakes from standing conifer trees as compound middle lamella failures, usually in latewood, with loose fibres and deposites of extraneous material on their shake surface.

- Handsplit and resawn shakes – a shake having a split face and a sawn back
- Tapersplit shake – a shake having two split faces and a natural shingle like taper
- Straightsplit shake – a shake having two split faces and with no pronounced taper

– *Split* a separation of the wood parallel to the fiber direction, due to the tearing apart of the wood cells.

## 2.3 Terms for the Delamination in the Cell Wall

The cell wall has a typical layered structure composing three main layers – $S_1$, $S_2$, $S_3$ – of variable thickness, in the micron (μm) range, composed of cellulosic microfibrils embedded in an amorphous matrix. Delamination can occur between layers as well as inside the same layer, and can be produced by growth related defects in living trees or can be a defect which develop in wood after it has been cut. Table 2.1 synthesises the terms related to the cell wall structure, describing wood delamination at the submicroscopic level.

The spectrum of terminology that has been used in profusion in the numerous articles cited in this table need to be put in concordance with the mechanical approach proposed in Chapters 3 and 4 of this book, for the description of phenomena related to the delamination in wood and wood – based composites. On the other hand, as noted by Wilkins (1986) the future nomenclature "needs to remain flexible and include further terms derived from the development of the tools for wood structure inspection". One can speculate about the contribution of new technologies for higher resolution microscopy in relation to wood ultrastructure which influence its mechanical behaviour.

## 2.4 Terms for the Delamination in Laminated Wood Products

Structural laminated products include plywood, various composites of veneer and of wood based laminates such as laminated veneer lumber, glued laminated lumber, wood fibre-reinforced polymer composites, etc.

Plywood as defined in ASTM D 1038 – as "usually a crossbanded assembly made of layers of veneer or veneer in combination with a lumber core or other wood-based panel material jointed with an adhesive. Plywood is generally constructed of an odd number of layers with grain of adjacent layers perpendicular to one another. Outer layers and all odd-numbered layers generally have the grain direction oriented parallel to the long dimension of the panel".