



Florentina Adriana Cziplé, António J. Velez Marques

Cell Walls of Wood, Composition, Structure and a few Mechanical Properties

The objective of this paper was to investigate the effect between the chemical composition, molecular architecture and structure cell walls of wood and the mechanical properties of wood. Cell walls function as the major mechanical restraint that determines plant cell size and morphology.

Keywords: *cellulose, hemicellulose, pectin, matrix polymers*

1. Introduction

The plant cells are encased in a complex polymeric wall that is synthesized and assembled by the cell during its growth and differentiation.. They enable cells to generate high turgor pressure and thus are important for the water relations of plants. Cell walls also act as a physical and chemical barrier to slow the invasion of bacteria, fungi, and other plant pests, and they also take part in a sophisticated signaling and defense system that helps plants sense pathogen invasion by detecting breakdown products from wall polysaccharides.

Finally, cell walls glue plant cells together and provide the mechanical support necessary for large structures (the largest trees may reach 100 meters in height, generating tremendous compression forces due to their own weight).

2. Cell Wall Synthesis

The components of the cell wall are synthesized via distinct pathways and then assembled at the cell surface. Cellulose is synthesized by a large, cellulose synthase enzyme complex embedded in the plasma membrane. This complex is large enough to be seen in the electronic microscope and looks like a hexagonal array, called a particle rosette because of its appearance.

The cellulose-synthesizing complex synthesizes thirty to forty glucan chains in parallel, using substrates from the cytoplasm. The growing chains are extruded to the outside of the cell via a pore in the complex and the chains then crystallize into a microfibril at the surface of the cell. In some algae the cellulose synthase complexes assume other configurations and this is associated with differing sizes and structures of the microfibril.

The primary cell wall contains three major classes of polysaccharides: cellulose, hemicellulose, and pectin. Hemicellulose and pectin collectively constitute the matrix polysaccharides of the cell wall (figure 1).

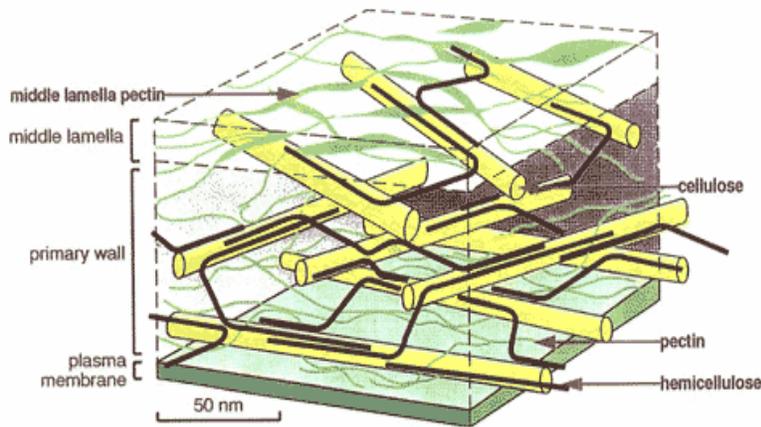


Figure 1. The *matrix polysaccharides*, hemicellulose and pectin

The *matrix polysaccharides*, hemicellulose and pectin, are transported to the cell wall via vesicles that fuse with the plasma membrane and dump their contents into the wall space.

The *matrix polymers* and newly extruded cellulose microfibrils then assemble into an organized cell wall, probably by spontaneous self-organization between the different classes of polymers.

3. Composition and Molecular Architecture

Cellulose is present in the form of thin microfibrils, about 5 nanometers in thickness and indefinite length. The cellulose microfibril is made up of many parallel chains of 1,4--glucan, which is a linear polymer of glucose molecules linked end-to-end through the carbon atoms numbered 1 and 4. These chains form a

crystalline ribbon that makes cellulose very strong and relatively inert and indigestible.

Hemicellulose refers to various polysaccharides that are tightly associated with the surface of the cellulose microfibril. They are chemically similar to cellulose, except they contain short side branches or kinks that prevent close packing into a *microfibril*. The backbone of hemicelluloses is typically made up of long chains of glucose or xylose residues linked end to end, often ornamented with short side chains. The most abundant hemicelluloses are xyloglucans and xylans. By adhering to the surface of cellulose microfibrils, hemicelluloses prevent direct contact between microfibrils, but may link them together in a cohesive network.

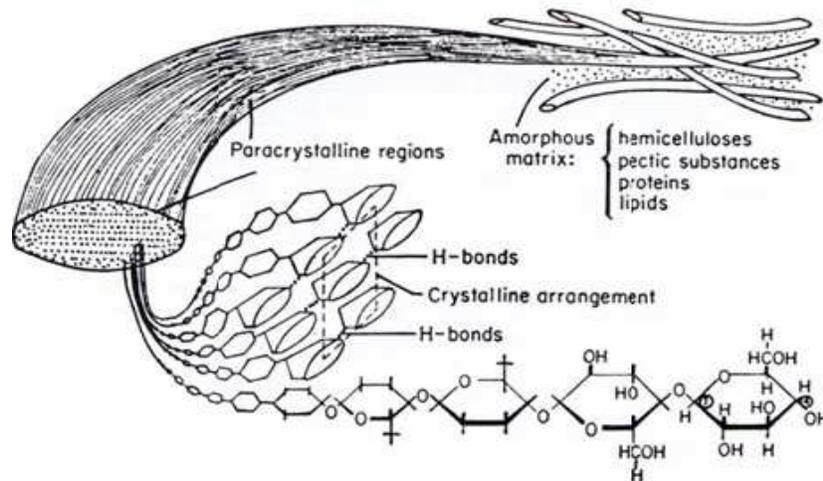


Figure 2. Composition and Molecular Architecture

Pectin constitutes the third class of wall polysaccharide. It forms a gellike phase in between the cellulose microfibrils. Unlike cellulose and hemicellulose, pectin may be solubilized with relatively mild treatments such as boiling water or mildly acidic solutions.

Pectin includes relatively simple polysaccharides such as polygalacturonic acid, a long chain of the acidic sugar galacturonic acid. This pectin readily forms gels in which calcium ions link adjacent chains together.

Other pectin polysaccharides are more complex, with backbones made of alternating sugar residues such as galacturonic acid and rhamnose, and long side chains made up of other sugars such as arabinose or galactose. In the cell wall, pectins probably form very large aggregates of indefinite size.

3. Structure of wood's cell

The plant cell wall is a remarkable structure. It provides the most significant difference between plant cells and other eukaryotic cells. The cell wall is rigid (up to many micrometers in thickness) and gives plant cells a very defined shape. While most cells have a outer membrane, none is comparable in strength to the plant cell wall. The cell wall is the reason for the difference between plant and animal cell functions. Because the plant has evolved this rigid structure, they have lost the opportunity to develop nervous systems, immune systems, and most importantly, mobility.

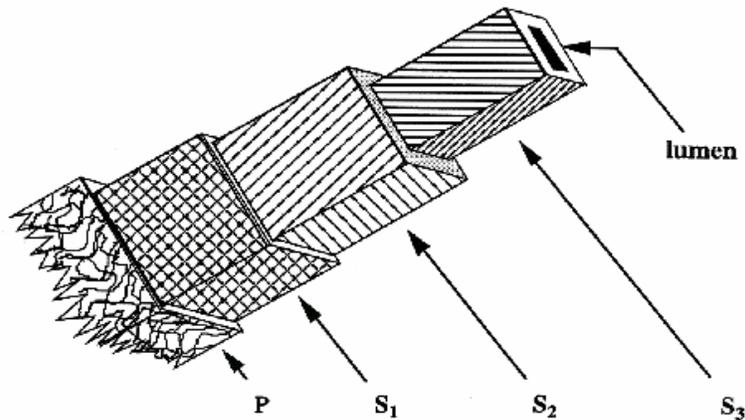


Figure 3. Schematic representation of wood fibre structure.
P: primary cell wall; S2: middle secondary cell wall; S1: outer secondary wall; S3: inner (tertiary) cell wall;

The cell wall is composed of cellulose fiber, polysaccharides, and proteins. In new cells the cell wall is thin and not very rigid. This allows the young cell to grow. This first cell wall of these growing cells is called the primary cell wall. When the cell is fully grown, it may retain its primary wall, sometimes thickening it, or it may deposit new layers of a different material, called the secondary cell wall.

Cell walls vary greatly in appearance, composition, and physical properties. In growing cells, such as those found in shoot and root apical meristems, cell walls are pliant and extensible (that is, they can extend in response to the expansive forces generated by cell turgor pressure). Such walls are called primary cell walls.

After cells cease growth, they sometimes continue to synthesize one or more additional cell wall layers that are referred to as the secondary cell wall. Secondary cell walls are generally inextensible and may be thick and lignified, as in the xylem cells that make up wood.

4. Nano-structure of the wood cell wall

Wood is a cellular material built up by tube-shaped cells oriented fairly parallel to the stem or branch axis. The wood cell wall consists of crystalline cellulose fibrils with 2.5 nm diameter embedded in an amorphous hemicellulose-lignin matrix and is organised in several layers. In the S2 layer which comprises the major part of the cell wall, the cellulose fibrils are aligned fairly parallel and trace a steep spiral around the cell.

The tilt angle versus the longitudinal axis of the cell is usually sharply defined and plays a key role in determining the mechanical properties of wood. At a given tilt angle, there are three possible orientations of the cellulose helix in the S2 layer: right handed, left handed or crossed lamellae.

Figure 4. The cellulose fibrils are aligned fairly parallel and trace a steep spiral around the cell. (source: *European synchrotron radiation facility (ESRF)*, Experiments Division / Microfocus, Grenoble Cedex, France)

The application of a new scanning X-ray microdiffraction technique allows the non-destructive determination of the helical orientation in several adjacent cells.

The measurements were carried out at the ESRF (European Synchrotron Radiation Facility, Grenoble, France) and yielded two interesting results: (1) the cellulose helix in the S2-layer is single, there are no crossed lamellae, (2) all the cells investigated showed a right handed (Z-) helix (figure).

5. Economic Importance of the Cell Wall

The cell wall is unmatched in the diversity and versatility of its economic uses. Lumber, charcoal, and other wood products are obvious examples. Textiles such as cotton and linen are derived from the walls of unusually long and strong fiber cells. Paper is likewise a product of long fiber cell walls that are extracted, beaten, and

dried as a uniform sheet.

Cellulose can be dissolved and regenerated as a manmade fiber called rayon or in sheets called cellophane. Chemically modified cellulose is used to make plastics, membranes, coatings, adhesives, and thickeners found in a vast array of products, from photographic film to paint, nail polish to explosives.

Pectin is used as a gelling agent in jellies, yogurt, low-fat margarines, and other foods, while powered cellulose is similarly used as a thickener in foods and as an inert filler in medicinal tablets.

References

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Addresses:

- Lecturer Dr. Eng. Florentina Adriana Cziple, "Eftimie Murgu" University of Reșița, Piața Traian Vuia, nr. 1-4, 320085, Reșița, cziple.chim@uem.ro
- Prof. Dr. Eng. António J. Velez Marques, ISEL, Lisbon Institute for Engineering, Portugal, avelez@deq.isel.ipl.pt