proposal

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1 Introduction to wood structure and formation

As trees grow they produce wood in order to become taller and wider. Becoming taller and increasing canopy size is an effective way to out compete the other trees and plants for light. With increasing height and width comes increasing weight, wind drag and internal pressures (for water transport), which requires either enough redundant strength in the existing structure (such as young monocotyledons) or for the tree to strengthen its structure as it increases its size. In dicotyledons and gymnosperms this occurs in two ways, apical and cambial growth on branches, roots and the stem(s).

Softwoods have a simpler micro structure than hardwoods, consisting mainly of axially elongated pointed cells named tracheids which serve as both mechanical support structures and water conduits. Although varying with species, softwoods may also contain radially orientated tracheids, radially or axially orientated parenchyma cells and other cell types. Tracheids are the dominant form of cells within the stems and branches.

Hardwoods contain a more complex micro structure with a number of different cell types. Fibres provide structural support as their primary function, while similar to softwood tracheids they differ in some key aspects, being shorter in the longitudinal direction, more rounded in the transverse outline, tend to have smaller lumens and have little role in sap ascent. However the ends do taper to points as in softwood tracheids. Libriform fibres tend to be longer than fibre trachiads, have thicker walls and are solely for support. Fibre trachiads function in both conduction and support, as in softwoods, however their appearance in wood with vessels suggests that they function primarily for support, and perhaps are an intermediate evolutionary feature between the softwood trachiad and the libriform fibre. Septate fibres devide their cell lumens into chambers without crossing the primary cell wall. Septate fibres are produced in the late stages of division just prior to the death of the cytoplasm, and appear to resemble axial parenchyma cells, and have been hypothesised to store starches, oils and resins.

Vessels are the main conduits for sap ascent. Vessels are comprised of multiple vessel elements being joined at the ends to form long conduits, which can

extend short distances (often less than 200mm) or can be as long as the height of the tree. These elements are connected through pores or perforations in perforation plates at the end walls of the cells. The arrangement of vessels into groups is species dependent and usually described as ring porous (the vessels congregate in early wood) or diffuse porous (vessels are distributed throughout both early and late wood).

Rays are formed from radially orientated cells often tracheids or parenchyma. Hardwoods typically contain multisteriate parenchyma rays, but there are a number of species with unisteriate or a combination of ray sizes, comparatively softwoods rearly contain multisteriate rays. Parenchyma ray cells are living within sap wood, however during the transition to heartwood die and are used for storage of extractives. Rays also provide a mechanical advantage by diverting the axial force flow reducing buckling and shear stresses between fibres.

Further cell types also exist, such as vasicentric tracheids which have profuse side wall pitting exhibiting deformation from the expansion of the surrounding vessels. Axial parenchyma cells are generally abundant and tend to exist in vertical files and are expected to play a role in the development of heartwood. More detailed wood anatomy and has little bearing on this project and is discussed in a number of wood anatomy texts.

In order to reorentat stems and branches of (most) trees produce reaction wood which provides a force in order to reorentat the tissue. Typicly this reorentation is toward the light or upwards as is defiend by the negative gravitrposim hypothesises. Other reasons for reorentation such as reduceing wind drag have also be sugested. In softwoods this reoretion is caused by the production of compression wood. Compression wood forms on the out side of the stem or branch and (expands? so that it is under compression? causeing a restoring force). Hardwoods on the other hand produce tension wood on the inside of the desired curve which (contracts?) resulting in a curve forming. Tradtionly the galaterness layer (G-layer), a layer primerally consisting of low angle cellulose fibrils on the inside of the fibre tracheids, is credited with forming growth stresses within the tension wood. However some hardwoods produce tension wood without producing a G-layer such as E Nitens.

Primarily, at different resolutions this work focuses on the fibre tracheids as they are the structual cells expected to be responcable for growth stresses in normal and reaction wood within hardwoods. The fibre tracheids consist of a number of cell wall layers depending on the species, the particualar cell and its primary function. Normal wood fibres within Eucalyptus species (CHECK THIS) consist of a middle lamaner (conecting the fibre to the sourding cells) a primary cell wall and a secondary cell wall consisting of S1, S2 and S3 layers (produced in coronalogical order so the exact composition will change depending on the cells developmental stage). The S2 layer is the largest layer and consists of cellullose macrofibrils wraped helicly around the cells longitudinal axis. This cellulose is contained within a matrix of hemicelluloses (examples) and lignin giving the cell wall properties of a fibre reninforced matrix. –how does this provide structure–

In order for the living cambrial cells to produce wood, each cell must go

through devision from its perant cell, growth and death. Because the cambriam (and apical merastem) are continually deviding it alows for the tree to be a dynamic structure changing its form to become better adapted to its current enviromental setting even though large portions (ie the wood) are dead. The transition form devision through elongation and development to death is expected to play a role in the development of growth stresses within the stem.

1.1 Basic cell division

Dicotyledons and gymnosperms grow in two main ways, upward apical growth and outward cambial growth.

Note monocotyledons (for example palms) do not produce secondary growth and instead diameter forms as part of primary growth.

As the cambium is forming, fusiform and ray initials are created. (how are the initials created) Fusiform initials are short radially and tangetialy with tapered ends. From the cambial initials, cells to the inside create the vertical elements of xylem (tracheids, vessels, fibers, parenchyma, etc.), while cells outside become phloem. Ray initials produce horizontal elements (rays).

Cambial cells divide in two ways, periclainal and anticlinal. Periclainal cell division occurs to the inner and outer of the cambial layers. As the cell division to the inside occurs the volume of secondary xylem that is being formed increases the tangential stress on vascular cambium resulting in an extention of the cambial circumference. Although over time many plants show an increase in the longitudinal and tangential dimensions of the cambial initials it is likely that this expansion is mainly facilitated by anticlinal division followed by the expansion of the daughter cells next to the pedant.

1.2 Cell formation, elongation and death

During primary wall formation rapid elongation occurs. When the cells devdie from their perants they remain fixed to their nabiours via the midel lamina. The intenal hydrostatic (turgor) pressure causes cell expantion. The osmotic flow of water from the outside the cell to the inside (due to a lower solute concentration outside the cell than in) which is constrained by the primary cell wall, the primary cell wall becomes under increasing tension as more water flows into the cell. Because the centre of the cell has restricted movment, in order for elongation (to disipate the increaseing tensile forces generated from the inflow of water) to occour the cell turns the biosythesis of cell wall constituants to produce tip growth. Growth at the tips of the cells allows for the cells to remain a cosntnat thickness, so no streching is needed during the elongation phase, as has been sugested previously. The expantion of the cells is suspected to be controld via modulation of the primary cell wall rather than via turgor pressure. – note that primary wall has randomly orentated MFs embeded in hemicellulose and pectic compounds and becomes lignified after S layer added , ML is non lignifed, note often compound middle laminer is used to describe the ML and P at once as are hard to distinguish— Once the cell has reached its full

size biosynthises of the S1 starts. Typicly the S1 layer is thin and comprises of —- The S2 layer bound to the inside of S1 is typicly much thicker and has more verticly orentated micorfibrils compeared to the primary, S1 and S3 layers ——. In some cases, most commonly in late wood an S3 layer is also produced —— Finally if tension wood is being produced a Gelatonus layer is produed on the indide if the inner most wall (S2 or S3). The G-layer has near verticly orentated microfibrils and very little lignification. It is suspected that the G-layer plays an important role in the generation of reorentation stresses. What is the deal with Rays—-

At some point during the formation of the seconday cell wall, or soon after the cell shrings verticly and expands tangentially. Because of the connectivness between cells this results in growth stresses forming within the stem, this phenomonan is descussed in greater detail in —-. After the seconday wall formation cell 'death' occours as part of the transition from sap wood into heartwood. While the hollow, dead cells play an importnat role in water transport and mechanical support of the tree, over time any residual nutrant that can be used by living cells— heatwood stuff—-

1.3 Cells and wood in the context of a whole tree

Wood as a materal within the tree has three major functions to achive; water transport, nutrant transport and mechanical struture. Softwoods achive water transport and mechancial struture within trachieds, while parenchima cells are used for nutrant transport. Hardwoods have evolved a more complicated internal structure of vessels and fibre tracheids in order to seperates out the functions of water transport and mechanical support respectivly.

–advantages and disavantages of this–

The growth stresses that form as part of cell formation are throught to provide a superiour mechanical structure. Because of the continual formation of new cells providing growth stresses on the perifery of the stem the older wood which has completed its formation and cell death must be contracted further with each new layer of cells atempting to contract. The result of this is the older wood near the centre of the stem becomes compressed while the newer cells can not contract to the extent that would leave them in their lowest energy state remain in tension, until the bond between the old wood and new is seperated releasing the forces restricting this contraction (and extention in the centre)

Reaction wood as described above provides the ability for the stem to reorentate in order to be best adapted to its enviroment at any given time.

These properties of wood allow for an adaptive organism to survive..

2 Introduction to growth stresses

It is suspected that growth stresses develop within trachieds during the formation the secondary cell wall, although the exact timeing and mechanisum for developing growth stresses is still of much debate. At current there a three

main competing theories, lignin swelling, cellulose contraction, and a hybrid of the two.

Most work early on in the study of growth stresses sorounded investigating why boards changed shape when cut from an intact stem. early work in 30s and related models/theories

quantification

archers work

lignin swelling Boyd 1972 compressive stress originating in the matrix refion pushes the CW tracheid whith a high MFA to expand

cellulose contraction wardrop 1965, bamber 1978 A tensile stress generated in teh cellulose MF forces the TW and NW fiber with low mfa to shrink.

hemicelluose theories

yamamotos recent model

issues with current understanding

2.1 Why growth stresses exist

Hardwoods typicly have much larger growth stress magnitudes than softwoods. –why–

speculation from various authors

Prehapse the leading argument for growth stresses existance is the mechanical hypothesis. The mechanical hypthesis argues that a number of wood properties, inclusing the development of growth stresses evolved in order to provide increase mechancial stability to trees in order to increase their servival. The mechanical hypotheisis as applied to growth stresses argues that because wood is stronger in tension than compression by preloading the outer edge of the stem in tension it increaseing the non-destructive bending radius on the inside of the curve when a force is applied causing the stem to bend. –dosnt explain why hardwoods have larger GS than softwoods.–

Other hypothsesis.

2.2 Intro to the issues growth stresses cause

for harvesting in extreme dangerous for feller splitting of log at felling internal checking

within mills bending/bowing/warping during cutting jaming up saws, large proportion of waste, multiple cuts required to get boards to desired dims

lost revenue final yield less than 30

3 Theoretical and experimental understanding of growth stresses

3.1 Background of breading

Because growth stresses cause a number of issues for harvesting and milling timber tree breading programs can be used in order to select for genetics which reduce these effects. –previous breading for GS– There is no reasion to expect breading for growth stresses differes significanly from (convetanally) breading trees for any other trait, which is process which has been developed over centries. Over the last few decades many advances have been made in experemental and statistical techneques which rapidly improve the time and acuracy of conventinal breading.

field techniques Typically breading trials, like any sciantific exprements are designed in order to minamise noise from uncontroled varables,

laboratory techniques

stat techniques

mention tradeoff with durability etc

3.1.1 Beading work in this thesis

What we actually have:

Harewood trial: dec 2014 has bosistoana and argophloia copiced from old planting that mon has GS data from. –from data can show (kind of as could argue same enviromental effects caused it) genetic relationship. New Harewood trial, 2016 harvest, will have a number of species potential to copice bos again if needed.

Woodvile, 2016/2017 harvest will have Bosistoana, argophloia and possibly globoidea. May or may not be the same families as the various drylands trials.

NOTE family means same mother, not same father. If collected at different times even from the same tree variability exists due to possibly of different set of fathers. Also some self propagate, but we don't know which ones or what proportion, so ignore this.

Progeny trials are alpha latauses, harewood is a standard randomised individual trial.

Contact Ruth McConnachie: rgcmcconnochie@xtra.co.nz for DFI details.

slit tests Pairing Test and Longitudinal Growth Strain: Establishing the Association 2008 is the earlyest paper I can find on the split/paring test. note kens papers from mon

surface tests

Potentually use NIR http://www.afs-journal.org/articles/forest/pdf/2002/05/05.pdf Has some useful info on wave lengths associated with bonds ic cellulose

Non-destructive evaluation of surface longitudinal growth strain on Sugi (Cryptomeria japonica) green logs using near-infraredspectroscopy

statistics

Progeny trials are alpha latauses, harewood is a standard randomised indervidual trial.

PLSR etc for NIR work

normal breading stats?

3.2 Background of chemistry work

lignin swelling

cellulose contraction

what has been done in the past? that xray syncotron experement etc

3.2.1 Chemistry work in this thesis

Do all of the DFI species have a G-layer? Maybe include some Nitens tests if they don't. check MFA and SD for S_2 in tension, normal and compression/opposite wood Get cellulose lignin and hemicellulose(s) contests for tension normal and compression/opposite wood Split hemicelluloses where possible, eg xyloglucan etc. Torsion tests on individual cells, again for tension, normal and compression. Maybe remove G-Layer in tension wood and compare to normal and compression wood of similar MFA and compounds etc.

Could we somehow measure growth stress release on a single cell? Ideally, grow disordered cells invitro, and separate them from the parent cell as soon as possible, then record when in their formation they undergo what dimension changes. Is there some non-destructive test to check what is going on in the cell? or if we have multiple cells in the same conditions maybe we can destructivly test some during the growth phase, under the assumption they are all growing at the same time. OR remove the cambial layer leaving top and bottom of cell attached to the stem on a large sample, then somehow remove the connection to the cells behind it, then release the top and measure the contraction.

3.3 Background of modeling

yammamotos most resent attempt

possible different methods ¿ FEM, DEM, molecular dynamics, gemomentry of stem and cells

3.3.1 Modeling in this thesis

cells as partials in relaxed state

apply body force, ie the growth stress field

get original/non cut stick back

take take groups of repressive cells and use composite theory and position dependent body force (growth strain field) from the sub domain above

introduce time dependence to see how the stress field develops during maturation, composite scale still – each cell can have its own clock so that it has a maturation rate to change its field variables.

take individual cells at macromolecular level and try to produce stress field above during a time dependent maturation function

Molecular dynamics simulations to work out the molecular mechanisms developing the growth stresses

Using the MD sims paramertorize a cell model

Using the cell model develop a time dependent field function

from the field function create representative cell blocks

put the cell blocks together into a stick

cut the stick ¿ do we get out what we put it?

4 Intentions

to improve breeding stock for NZ dryland forestry with respect to eucs being used for structural timber

to increase understanding of growth stress formation particularly in eucalyptus by chemical analysis and computer modeling

5 Objectives

to create a mathematical model and computer simulation of a piece of cambium forming growth

stresses at the macromolecular level

to investigate the chemical causes of GSs by chemical analysis ¿¿ how?

to improve breeding stock for eucs wrt growth stresses from field and lab testing to select appropriate families.

6 Costs

7 Timeline