A REVIEW OF WOOD-BARK ADHESION: METHODS AND MECHANICS OF DEBARKING FOR WOODY BIOMASS

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Abstract. Debarking systems and strategies are used to increase the value of woody biomass by separating wood and bark into two value-added product streams. Several debarking methods have been used for the removal of bark from wood. The selection of a debarking method is often based on the wood type and its end use. Debarking methods discussed briefly in this review include drum debarking, ring debarking, cradle debarking, chain flail debarking, high-pressure water jet debarking, compression debarking, and bio-debarking. The performance of these debarking methods is highly dependent on operational parameters of machines, properties and type of woody biomass, and pretreatments. A universal applicable mechanistic model of the debarking process would be especially valuable for the development and optimization of debarking systems. In this respect, the competing objectives of high bark removal, low wood damage, high throughput, and low energy must be balanced against one another to arrive at a truly optimized approach. Wood-bark bond strength plays a vital role in impacting the effectiveness and efficiency of debarking technology. Thus, it is important to understand how mechanical properties of the wood-bark interface are influenced by different factors. Key factors that affect the wood-bark bond strength include MC, harvest season, wood species, temperature, and direction of applied load. The likely reason why MC affects the wood-bark adhesion strength is that the constituent elements of primary plant cell walls (cellulose, hemicellulose, and pectin) behave differently when they are exposed to water molecules. For example, there is negligible change in the length if cellulose microfibrils when exposed to water molecules. However, characteristics of hemicellulose and pectin behave differently than cellulose when they contact with water molecules. Also, the difference in the adhesion strength of wood-bark bond among varieties of woody plants is possibly due to the difference in density of cross linkages of homogalacturonan pectin by Ca^{2+}, and arabinan and galactan side chains of pectin. The relevance of this information to the debarking process is discussed.

Keywords: Cambium, debarking, lignocellulose, plant cell walls, pectin, wood-bark adhesion.

INTRODUCTION

"Debarking" is the process of removing bark (material above the vascular cambium) from the wood stem (Nurmi and Lehtimäki 2011). Effective debarking can improve the utilization of woody material and enhance the quality of final products by minimizing wood loss and providing an additional value-added product in the form of separated bark. In practice, debarking does not necessarily make the wood completely bark-free. The acceptable fraction of bark remaining on a debarked wood stem depends on the final use of the wood, which decides the bark tolerance for debarked wood (Koch 1983; Baroth 2005).

Debarked wood has a different chemical composition and unique mechanical properties when compared with undebarked wood. For example, debarked wood from shrub willow, a short

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rotation woody biomass crop, has a significantly greater portion of cellulose and lower lignin content (Serapiglia et al 2009). Bark is high in lignin content (25-45%) and lower polysaccharides compared with wood. However, wood has a higher heating value of approximately 20 MJ/kg compared with 19 MJ/kg for bark. The concentration of inorganic elements and ash is higher in bark than wood, approximately 1.9 times and 13.5 times as high for P and Na, respectively (Tharakan et al 2003). The average ash content of stem bark ranges from 4.8 to 6.0% by mass and 0.52 to 0.89% by mass in wood stem. The total extractive content of the bark ranges from 31 to 39% compared with approximately 10% in the wood (Kenny et al 1990).

The processing of wood is more effective when wood is homogeneous. The function of automated machines (often laser-based scanning and optimization systems in sawmills) improves for debarked logs. The performance of biomass conversion into biofuels also increases with the use of homogenous woody biomass (Nurmi and Lehtimäki 2011; Jacob et al 2013). Debarked wood is more desirable for variety of purposes. For example, the pulp and paper industry uses bark-free (or very nearly so) chips. Mechanically, static bending strength of whole willow twigs is approximately 50% less than that of debarked willow twigs, which is relevant to any structural applications of the material (Wiaderek and Waliszewska 2010). Debarked wood also tends to dry faster compared with wood with bark fraction. Moreover, the separated bark can be used as a source of fiber, tannins, dyes, gums, resins, latex materials, foodstuffs, flavorings, antibiotics, and as a medicinal product (Harkin and Rowe 1971). Bark is high in extractives; for example, willow bark contains extractives such as salicylic acid, which has pharmaceutical value and can be used as an anti-inflammatory, antipyretic, and analgesic (Shara and Stohs 2015). One common use for bark is mulch. The decomposition rate of bark is slower compared with wood; hence, it lasts longer as mulch and will have lower nitrogen consumption when incorporated into the soil. Therefore, managing and dealing with wood-bark separation is important, both to enhance the value of wood and to create an additional value product from bark. Removal of bark depends on several factors that include the type of equipment being used, log form and variability in the adhesion strength at the wood-bark interface. This article reviews major types of debarking technologies and the key factors that can influence the wood-bark adhesion strength.

DEBARKING TECHNIQUES

Several debarking techniques are used in the timber industry to separate wood and bark. The selection of a technology is often based on the type and processing of wood. Some common debarking techniques used to separate bark from wood include drum debarking, ring debarking, cradle debarking, flail debarking, high-pressure water jet, compression debarking, and biodegradation (Gupta et al 2015). In most cases, applied loads serve to weaken the wood-bark bond via mechanical damage and/or separate the bark from the wood.

Drum Debarking

Drum debarking is one of the methods used in the timber industry to separate bark from wood. The tumbling action produced by logs placed inside a rotating drum can abrade the logs against other logs and against the drum surface, dislodging bark from the wood. In this technique, a cylindrical drum is fitted with slots and mounted at slight incline. The logs are fed in the higher side of the drum and are discharged as debarked wood from the other end. The separated bark falls through the slots in the shell of the drum. Retention time of the logs inside the drum can be controlled by closing the exit gate partially. If debarking time is too short, the logs remain partially debarked, and if it is too long, then it leads to wood loss (Isokangas et al 2006). The residence time of wood in a drum debarker can be expressed by the equation (Isokangas and Leiviska 2005):

$$T = \frac{V}{F}.$$

T = residence time,
V = volume of wood in the drum,
F = flow rate of wood in the drum.

The completeness of debarking and wood loss is influenced by several other factors along with residence time. This includes rotational speed (rpm) of the drum, de-icing in the winter and water treatment during summer, structure of the drum (diameter, length, and declination angle), and wood properties. For example, high wood-bark shear strength resulting from low MC can be responsible for poorly debarked logs (Oman 2000). Likewise, damage to the wood can also influence the debarking process in drum debarking. In cold climates, steaming might be valuable to incorporate with drum debarking for effective wood-bark separation.

Rotary Ring Debarking

In a rotatory ring debarker, an array of swing arm knives is mounted to a rotatable ring that scrapes the bark off the logs as they are fed through the ring. Like drum debarking, there are some operating parameters that affect the performance of ring debarker including radial force, log feed speed, ring rotational speed, and log overlap (Ding et al 2012). In mills, radial force (the force applied by the swing arm to the log) is decided according to wood species, log diameter, and log-condition (frozen or nonfrozen). Laganiere and Hernandez (2005) report the effect of radial force and tip path overlap, indicating that there is a significant effect of static radial force on bark removal. A decrease in radial force results in more bark remaining on logs. Soaking the logs in warm water improves the debarking performance significantly. Bassler (1987) reports the successful debarking of wood stems down to three-inch top diameter using a rotatory ring debarker. However, the processing speed of debarking logs is inversely related to diameter. Ring debarkers are commonly used in the timber industry. The initial investment in a ring debarker is comparatively lower than drum debarkers and power requirements per cubic foot of wood debarked are less (Koch 1983).

Rosser-Head Debarking

Similar to ring debarkers, rosser head debarkers are used in many mills to debark sawlogs and veneer logs that are difficult to debark with ring debarkers. The cutterhead of a rosser head debarker has plurality of rounded cutting teeth spaced in repeated rows running axially the length of the cylindrical surface. The logs revolve on their axis while being fed longitudinally and the shear action between log and teeth removes the bark from those logs.

Cradle Debarking

A cradle debarker is essentially an enhancement to traditional closed drum design. In cradle debarking, vertical conveyers raise and then drop the tree logs, inducing compression and shear forces that result in the separation of bark from stem. It features an open design that permits the operator to tailor the debarking process based on the species of tree debarked. The abrasion action is produced between logs and as well between logs and conveyors, resulting in removal of bark (Gupta et al 2015).

Chain Flail Debarking

In chain flail debarking, hard chains mounted on a rotating shaft shred the small branches and bark off the tree trunk. Chain flail debarkers can process multistem trees. However, they tend to damage more wood than is preferable for timber, which means that its use is often restricted to whole tree chipping and pulpwood production. The estimated cost of flail chain debarking operation ranges from US$0.60 to US$6.30 per ton of chips processed (Watson et al 1993). Rotating chain speed, feed rate, tree size, tree species, number of branches, and condition of the flail chains all impact the quality of delimbing/debarking (Thompson and Sturos 1991; Watson et al 1993; Hartsough et al 2000). McEwan et al (2017) conducted a study to observe the influence of various factors affecting the productivity and work quality of chain flail delimbing and debarking. They measured the average productivity to be 74.7 m^3 per productive machine hour, although productive work time was only 81% of total worksite time. Delimbing-debarking time (time when chain flails are hitting the stems) is 83% of the productive work time or 67% of the total worksite time.

High-Pressure Water Jet Debarking

High-pressure water jet debarking is not a commonly used debarking technology, but it has the potential to separate bark from wood (Gupta et al 2015). In this approach, high-pressure jets are used to scrape the bark off from wood. A trunnion wheel supports and rotates the individual logs. This technology has potential to be used on wide varieties of logs; small to large logs and easy to difficult debark species. One downside of this technique is the use of water, which might be reduced by filtration and recirculation of water to minimize its consumption (Grobbelaar and Manyuchi 2000).

Compression Debarking

Although most debarking systems only work well for whole logs, compression debarking is a suitable method to remove bark from chipped wood. In this technique, wood chips with bark are compressed between closely spaced steel rollers rotating in opposite directions. The pinching action of the rollers induces stresses in the bark that cause it to delaminate from the wood. A screening step then separates the wood from the bark. Separation of bark from wood by this method is more efficient when wood chips are presteamed before being compressed between the steel rollers (Sturos and Erickson 1977). The compression debarker can remove around 50-70% of the bark from chip mass, and with the addition of presteaming, an additional 20% bark can be removed (Mattson 1974).

Biodebarking/Biodegradation/Chemical Debarking

Another debarking technique used to remove bark is biodebarking in which microorganisms weaken the nonlignified cambium faster than adjacent bark and wood. Biodebarking might be more accurately classified as a pretreatment, as additional processing is usually needed to separate the bark from the wood. Conditions that favor bark-wood separation via biodebarking are the conditions favorable for the growth of microorganisms or fungi (Kubler 1990). For example, the pectinolytic enzymes that degrade the cambium layer of spruce can result in an 80% reduction of energy consumption during debarking (Ratto et al 1993). The application of chemicals such as sodium arsenite might aid in debarking (Gammage and Furnival 1957). These debarking techniques might be preferable for small-diameter stems, as those stems might have more wood loss during mechanical debarking. For example, using a flail debarker on larger trees with more than 50 kg total dry mass, the average potential of wood recovered is 75% of total weight. By contrast, only 50-75% mass fraction is recovered from small trees (those are less than 50 kg of total dry weight).

Many of the debarking technologies in use today in the timber industry are based on brute force technology where the bark is simply scraped off the wood with large metal prongs. The performance of these debarking techniques is affected by key factors, including operating conditions of the machine, type of wood, properties of wood, and pretreatments. Some research has been carried out to characterize the performance of successful debarking systems, but rigorous characterization and comparison is still needed. Debarking technology may be considered old and mature, but much is still not known about these systems, and opportunity for optimization and improvement still exists. Also, future changes to the wood industry, for example, the growth of the biomass sector and development of short rotation woody crops, are likely to open up new opportunities for novel approaches to debarking. Therefore, further study is needed to better characterize the mechanical performance of these systems that allows meaningful comparison and optimization of debarking systems and strategies. In this respect, the competing objectives of high bark removal, low wood damage, high throughput, and low energy use must be balanced against one another to arrive at a truly optimized approach. A universally applicable mechanistic model of the debarking process would be very valuable in this respect for the development and optimization of debarking systems. These mechanistic models can examine the impact of individual components and the manner in which they are coupled for assessing overall system performance. For example, mechanistic model could characterize the impact of loading rate on debarking degree and provide an estimate of the energy consumption so that operating parameters could be optimized for various wood species. The model can also be used to characterize the impact of storage time on debarking for optimizing the harvesting and processing of woody biomass. Some key factors that influence the strength of wood-bark bond and can impact the effectiveness and efficiency of debarking technology are discussed in the next sections.

PHYSIOLOGY OF SEPARATION/FRACTURE PLANE

Mechanical failure associated with debarking mostly occurs in the cambial zone or on either side in the phloem and xylem differentiating zones (Gurusinghe 1994). Because of this, the properties of the cambium zone are of especial relevance to the debarking process. Failure can occur through the cell walls or along the boundary between cells. Thus, debarking is likely to be impacted by cell wall strength and/or cell-to-cell adhesion properties. In the cambium, cell walls are thin and tend to be easy to shear under external load. The composition of main constituents (such as carbohydrates) of the cambial cell wall is similar in all woody biomass (Thornber and Notrhcote 1961). The chemical and sugar composition of inner bark (representative of the cambium zone) and wood of shrub willow is given in Table 1. In general, the inner bark has lower sugar levels but higher extractive and ash content. Better understanding of the composition and properties of cambium region relative to debarking will help characterize the controlling mechanism of debarking from micro- and nanostructural point of view, which can influence the debarking strategies and also provide opportunities to breed new varieties that are conducive to effective debarking.

Table 1. Carbohydrate composition (mean percentage of anhydrosugars in the original dry mass) (Dou et al 2016).

Chemical composition (%)			Sugar composition (%)		
	Inner bark	Wood		Inner bark	Wood
Sugar	38	60	Arabinose	6	0.8
Lignin	18	23	Rhamnose	1	0.8
Extractives	23	4	Galactose	4	2
Ash	7	1	Glucose	29	42
Others	14	12	Xylose	6	15
—	—	—	Mannose	2	3

Primary cell walls in the cambium are composed of polysaccharides (approximately 30% cellulose, 30% hemicellulose, and 35% pectin) and 5-10% remaining polysaccharide-modifying protein (Villarreal et al 2012; Vogler et al 2015). These polysaccharides provide the mechanical strength to the cells, protect cells against biotic and environmental stresses, and allow cell-cell adhesion (Somerville et al 2004; Morán et al 2008; Voragen et al 2009; Villarreal et al 2012; White et al 2014). The main component of the primary cell wall and middle lamella/reinforcing zone, pectin, is very hydrophilic. Pectins influence cell wall properties such as porosity, surface charge, and ion balance and are likely to be a major factor in cell-cell adhesion in plants (Parker et al 2001; Hoffman et al 2005; Voragen et al 2009). The adhesion properties of pectin may be associated with the cross-linkage of calcium cations to negatively charged portion of pectin molecules (Fry 2004; Caffall and Mohnen 2009; White et al 2014) and the presence of arabinan and galactan side chains (Daher and Braybrook 2015). A high amount of monosaccharides from pectin (arabinose, galactose, and rhamnose) are present in inner bark compared with wood (Dou et al 2016).

FACTORS AFFECTING BARK-WOOD ADHESION

Wood-bark adhesion strength is influenced by several factors. Knowledge of these factors can aid in the development of effective and efficient debarking systems and strategies by guiding selection of an appropriate debarking technique for a particular feedstock, storage condition, storage time, and harvest time. Key factors that can affect the bark-wood adhesion strength include MC, harvesting season, wood species, temperature, and direction of applied external force.

Moisture Content

The adhesion strength of wood-bark is negatively correlated to MC (Rowell 1984; Moore 1987; Duchesne and Nylinder 1996; Baroth 2005). It is believed that changes in MC affect wood at a micro level in a manner that changes bark-wood adhesion strength (Gurusinghe and Shackel 1995). Gurusinghe (1994) reports a negative correlation of cambium tissue hydration with bark-wood adhesion strength. The typical relationship observed between shear strength of wood/bark and MC of sapwood is nonlinear with most variation occurring between 20 and 40% MC as shown in Fig 1 (Duchesne and Nylinder 1996). The nonlinear change in shear strength of wood-bark bond with MC might be due to the evolution of pores' topography, in which the structure of polymers evolves in such a way that the average pore size increases and pores might merge (Kulasinski 2016).

Lignocellulose microstructures within wood and bark tend to respond in an orthotropic and heterogenous manner, with cellulose microfibrils, hemicellulose, lignin, and pectins all responding differently and with a longitudinal response that differs markedly from the transverse direction (White et al 2014). The layered microfibril's structure with long cellulose chains is almost inert in its longitudinal direction during addition of water molecules because two-third of hydroxyl groups are bound in the cellulose interchain, making the microfibrils relatively inaccessible (Hofstetter et al 2006). However, matrix polysaccharides of cell wall, namely, hemicellulose and pectin, are relatively agile in relation to their response to water molecules (Hediger et al 1999). Moreover, the hydraulic conductivity of the cell wall correlates with changes in pectin network porosity (Bidhendi and Geitmann 2016). The difference in physical properties of cell wall polysaccharides leads to motional heterogeneity that might affect the deformation of cell walls under applied load. The deformation of cell walls is described as slippage between the microfibrils, which is facilitated by breakage and reestablishment of hydrogen bonds (Engelund and Svensson 2010), which could also affect the mechanical properties of cell wall layers. In addition, one or more constitutive materials might undergo glass transition during sorption from one equilibrium state to another (Ha et al 1997; Engelund et al 2013). These variations of mechanical characteristics may cause the initiation of fracture due to uneven stress distribution under external loading. In-depth understanding of cell wall physiology might not be directly applicable to current brute force–based debarking processes. However, it can be used to advance the understanding of structures and properties of wood that can eventually be useful for guiding successful debarking strategies and systems down the road. For example, plant breeding and selection of chemical treatments for debarking can be both guided by a molecule-scale understanding of the bark-wood bond.

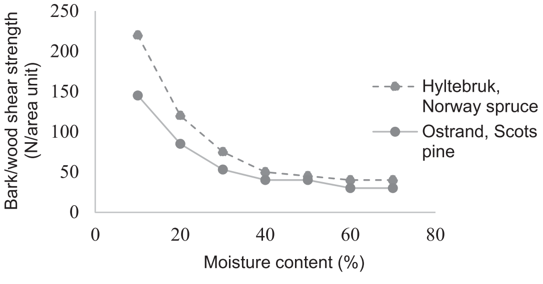

Figure 1. Typical relationship between shear strength of wood-bark and MC (Duchesne and Nylinder 1996).

Seasonal Variations

The adhesion strength of wood-bark bonds tends to be higher in the dormant season compared with the growing season (Einspahr et al 1982; Prislan et al 2011). Shear strength of the wood-bark bond during dormant season can be more than twice that of the growing season (Vilkovsky et al 2016; Vilkovsky and Cunderlik 2017). In hardwood species, the shear strength of the wood-bark bond varies between 706-3006 kPa during dormancy but is as low as 245-628 kPa during the growing season (Gurusinghe 1994). A representative view of the wood-bark interface (xylem-cambium-phloem) during growing season and dormant season is shown in Fig 2. The cambium zone is noticeably narrower during dormant season compared with the growing season. In the growing season, phloem rays are composed of nonlignified thin wall parenchyma cells that are easy to shear under applied load, whereas mature (dormant season) phloem rays (which consist of seven or more ray cell layers) included thick-walled sclerenchyma cells that are not easy to shear when loaded. These sclerenchyma tissues are often pulled out from wood rather than being torn (Silva and Ueki 2010).

Wood Species and Morphology

The wood-bark bond adhesion strength varies among plant genotype, as shown in Table 2 (Baroth 2005).

Several characteristics are important to mechanical strength of wood-bark bond that are likely related to variation in morphology from species to species, including wood-specific gravity, bark-specific gravity, percent bark fiber, percent sclereids, wood toughness, total bark strength, and inner bark strength. The presence of sclereids shows a negative correlation with the mechanical strength of wood-bark bond (Einspahr et al 1982). However, some hardwood species are exceptions to that trend. The rigidity of sclereids might affect the distribution of stress on cell walls and middle lamella (Jarvis 1998). For example, if the cell wall is rigid, then it can only bend to a relatively large radius which might induce cells to separate when subjected to an external load (Silva and Ueki 2010).

Along with these morphological differences, the controlling mechanisms behind the variation in wood-bark adhesion strength between the wood species may be related to mechanical properties of the primary cell walls and reinforcing region (middle lamella). These mechanical properties depend on the arrangement and interaction of structural components (Jarvis 1984; Salmen 2004; Eder et al 2013; Shafayet et al 2017). A large fraction of primary cell wall and middle lamella consists of pectins (Jarvis et al 2003) that contribute to water-holding capacity and adhesion of plant cells (Voragen et al 2009). Some alteration of pectins either by pectinase treatment or genetic modification can reduce the demethyl-esterification of homogalacturonan (HG) and increase wall porosity (Baron et al 1988), which correlates with accessibility to wall components for degradative enzymes that enhance the process of biomass saccharification (Lionetti et al 2010; Xiao and Anderson 2013). This suggests that

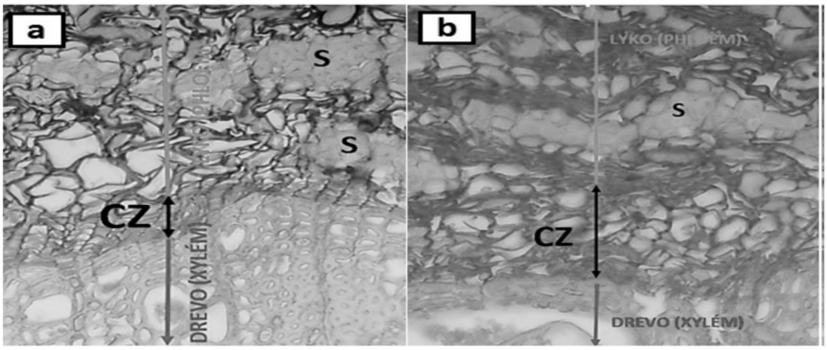

Figure 2. Cross section view of bark-wood interface (xylem-cambium-phloem) during (a) dormancy and (b) growing period. Sclereids, CZ, cambium zone (Vilkovsky et al 2016).

Table 2. Wood-bark adhesion strength among different varieties of woody plants (Baroth 2005).

Wood species	Wood-bark bond strength (kPa)
Basswood	approx. 2070
Beech	482-758
Birch	810-1080
Black poplar	1170-1380
Elm	810-1080
Ironwood	1170-1380
Hemlock	482-758
Hickory	approx. 2070
Maple	275-380
Southern pine	275-380
Spruce	482-758
White pine	482-758

varieties with high porosity and easy access to degradative enzymes can possibly be structurally weak.

At a molecular level, de-esterification of pectin changes the mechanical properties of cell walls (Bidhendi and Geitmann 2016). The unmethylated C-6 of HG GalA residue is negatively charged and ionically interacts with Ca^{2+} to form a stable gel with other pectin molecules (Caffall and Mohnen 2009). Calcium cross-linking of HG, bridging the blocks of unmethyl-esterified HG chains, can contribute to intercellular adhesion (Willats et al 2001). Membranes cultured in low Ca^{2+} were found to be structurally weakened (Hapler 2005). Reduced calcium and RGII cross-linking in the cell wall also increases the xylem vulnerability to cavitation, extractability of cell wall sugars, and increased growth (Cochard et al 2007; Biswal et al 2018). Therefore, it is likely that varieties which are more accessible to degradative enzymes are structurally less integrated because of low Ca^{2+}, resulting in weak adhesion between cell walls.

Temperature

In general, the strength of wood is higher in cooler temperatures and lower in warmer temperatures. The immediate effects of increased temperature might be an increase in the plasticity of the lignin and an increase in spatial size, which reduces intermolecular contact. In addition, increasing temperature might also affect the mobility of heterogeneous constituent composites of the primary cell walls (White et al 2014), resulting in the variation in mechanical properties of the bark-wood interface.

At temperatures below −2°C, the adhesion strength of bark-wood bond for moist (>30% MC) samples is three to five times higher than the strength of bark-wood adhesion at room temperature, Fig 3 (Duchesne and Nylinder 1996; Prislan et al 2011). The adhesion strength is curvilinearly and negatively correlated to MC at temperatures ranging from −20 to −40°C. This might be due to partial freezing of the cambium, as high protein and pectin levels in cambium cells inhibit the complete freezing of the cambium (Chow and Obermajer 2004). However, cambium cells are completely frozen when temperature reaches −78°C, and the shear strength of wood-bark interface is high due to the added strength of the solid ice crystals.

Directional Variation

Wood is an orthotropic material, whose mechanical properties vary along three principal axes: longitudinal, tangential, and radial. Likewise, mechanical properties of wood, including adhesion strength of wood-bark, are observed to be different in the perpendicular axes. The wood-bark adhesion strength in the longitudinal direction is higher than in the transverse direction of wood, by about 15% (Gurusinghe and Shackel 1995). Results are similar in either season: growing or dormant (Vilkovsky et al 2016; Vilkovsky and Cunderlik 2017). High

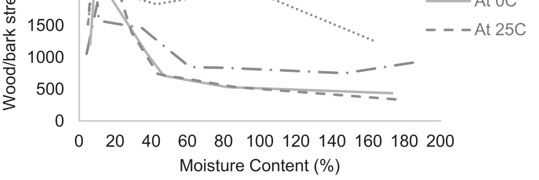

Figure 3. Wood-bark adhesion strength vs MC affected by temperature (Duchesne and Nylinder 1996).

mechanical strength of wood in the longitudinal direction can be due to the microfibrils' alignment in the longitudinal direction of wood (Engelund et al 2013). In addition, the orientation of those microfibrils can be responsible for the difference in swelling and shrinkage in three perpendicular planes. Swelling in the longitudinal direction of softwood is significantly lower than in the transverse direction (Derome et al 2011) because microfibrils are aligned in longitudinal direction such that they limit the accessibility of hydroxyl groups (present in linear chains of cellulose) to water (Engelund et al 2013). Also, the variation in swelling and strength of wood in radial and tangential direction might be impacted by the restriction of ray cells, which are oriented in radial direction of wood. This information can be valuable while orienting the logs during debarking or when designing systems that are not able to orient the wood before processing (ie debarking of chips).

CONCLUSION

Debarking increases the value of woody biomass by separating wood and bark into two product streams. Debarking systems and strategies are influenced by the choice of debarking technologies, properties of woody plants, and pretreatments. The performance of a debarking technique can be controlled by operational parameters that include log feed rate, machine speed, and compression pressure in compression debarking. The bark is scraped off from the wood fraction by the shear action in most debarking techniques. A validated mechanistic model would be very valuable in the characterization of successful debarking systems and be used to optimize the debarking systems and strategies. These mechanistic models can evaluate each component and component in a certain way that might have influence on system performance and economic viability of debarking.

Under external load, wood and bark usually separates at the growing region known as the cambium region. The cell walls in the cambium region are thin and easy to shear when external load is applied. The composition of primary cell walls in the cambium is approximately 35% pectin, 30% cellulose, 30% hemicellulose, and 5-10% remaining polysaccharide-modifying protein. To enhance the performance of future debarking systems and strategies, it is important to understand the mechanics of wood-bark bond. Wood-bark adhesion strength is affected by MC, which is possibly due to the constitutive materials of plant cell walls that respond differently to addition of water molecules. Wood-bark adhesion strength among varieties of woody plants is lower in growing season harvested wood compared with the dormant season harvested wood. Phloem rays in the growing season are composed of nonlignified thin-walled parenchyma cells and are easy to shear, whereas mature phloem rays have thick-walled sclerenchyma cells and are not easy to shear under external load. Temperature and direction of applied load also affect the wood-bark adhesion strength of different varieties of woody plants. The adhesion strength of wood-bark bond is also different among varieties of woody plants. It is likely that the variation in adhesion strength of wood-bark bond among the varieties is due to differences in density of cross linkages of calcium ions and the presence of arabinan and galactan side chains of pectins. Understanding the mechanics of wood-bark adhesion strength can lead to a conceptual model of the debarking process that could guide future work in this area and be the gateway to effective and efficient debarking systems and strategies for woody biomass.

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