FPInnovations
319 Franquet Street
Québec, Québec G1P 4R4

Transformative Technologies Program
Project No. TT4.3.03
201005167

Element 4: Hardwood Initiative — Development of new processes and technologies in the hardwood industry

Best Practices to Avoid Hardwood Checking
Part I. Hardwood Checking – the Causes and Prevention

by

Dian-Qing Yang and Dany Normand
Research Scientists
Lumber Manufacturing Department

March 2012

Dian-Qing Yang	Dany Normand	Francis Fournier
Project Leadeer	Reviewer	Department Manager

Abstract

Wood checking is a major problem that has a significant economic impact for hardwood producers and consumers. Wood checking can occur on logs, green lumber, dried lumber and final products during manufacturing, drying process, storage and end-use. Checking on wood products is caused by many internal and external factors such as wood species, moisture content, storage method, drying process, temperature, relative humidity, air flow velocity and solar radiation. While it is impossible to completely eliminate wood checking; it however can be controlled to an acceptable level with proper measures. The control measures include best practices in harvesting, storage, sawing, drying, chemical coatings, physical methods and controlling end-use environmental conditions. This report provides scientific information on the nature of different types of checks that may occur on various wood products, checking conditions and control measures.

Table of contents

List of Figures

1 Objectives

To maximize volume and value return of hardwood production, and to provide best practice guidelines to avoid checking development on hardwood products.

2 Introduction

Wood checking is a common and important physical defect in hardwood manufacturing (Wilhelmsen 1969). Wood checking is mainly caused by stresses created by external physical impact or internal unequal shrinkage. It occurs in logs, green lumber, dried lumber, components and final products during manufacturing, drying, storage and end-use. The amount of checking on wood products depends on many internal and external factors such as wood species, moisture content, amount of knots, natural defects, dimension, drying, storage method and environmental conditions of wood manufacturing and end-use. The environmental conditions that influence wood checking are temperature, relative humidity, air flow velocity and solar radiation. Wood checking reduces the volume of converted products from sawlogs and degrades lumber value. To minimize wood checking, the knowledge of check development mechanisms on various wood products, proper manufacturing and drying processes, and different control measures are required. This report is the first part of the project and it provides hardwood manufacturers with basic information on different types of wood checks, their forming conditions and known control measures from a literature review.

3 Staff

Dian-Qing Yang	Wood Protection Scientist
Dany Normand	Wood Drying Scientist

4 Check Development in Logs and Lumber

4.1 Definition of wood check

The definition of wood check is fairly clear with slight wording differences throughout the literature. In a popular booklet of Standard Grading Rules for Canadian Lumber, which was published by National Lumber Grades Authority of Canada (NLGA, 2010), checks are defined as "A separation of the wood normally occurring across or through the rings of annual growth and usually as a result of seasoning". Whereas in another booklet called Rules for the Measurement & Inspection of Hardwood & Cypress, which was published by National Hardwood Lumber Association of USA (NHLA, 2011), wood checks are defined as "A lengthwise separation of the wood that usually extends across the rings of annual growth and commonly results from stresses set up in wood during seasoning". Because checks are formed in wood during seasoning, they are often called "seasoning checks".

4.2 Causes of wood checking

Checks are longitudinal openings at weak points in the wood caused by the stresses produced in differential shrinkage (Kolleman and Côté 1968). Shrinkage is a nature character of wood, and it is created by loss of bound water inside of wood fibres. The shrinkage in wood cells begins at the fiber saturation point (25 to 30% MC) and it is a gradual process. The differential shrinkage in the wood can be explained by three mechanisms:

1) During seasoning or storage, wood dries from the outside to inside and bound water of outside wood is gone before core wood, causing outside wood to shrink while the inside wood does not. The shrinkage of outside wood creates stress that is released by forming cracks in the surface wood, which are generally called checking.
2) The difference in shrinkage exists also between the radial and tangential directions of the wood. The shrinkage is more important in tangential direction than in radial direction.
3) An important difference of shrinkage is also present between the normal wood and the reaction wood. The shrinkage of the reaction wood (compression and tension) in the longitudinal direction is more important than in normal wood.

Species with large rays are more sensitive to checking. Checking tendency is greater in oak and beech than in birch. Remember, the weakest part of the wood is along the rays. The wood is weaker than normal wood also by other reasons like: bacteria or fungi infected wood and mineral streaks.

4.3 Checking in logs

Log bark prevents water loss; therefore, it protects trunks from checking. Most checks are formed at log ends or debarked part of logs. When bark is loose or dropped from logs due to the moisture loss, no protection is provided and checks will appear on whole log bodies. Massive checking on logs is often associated with excessive storage time during the hot season.

In all wood species, logs shrink more in radial and tangential directions than in longitudinal direction. Because most shrinking occurs across the log diameter and wood is the weakest in tension across the grain, checking generally occurs longitudinally along wood grain. In a log, one or several large primary checks may develop along with many small secondary checks. The primary checks may penetrate from the outside into the center of a log and the location in logs can be uncertain. In log house construction, the location of main checks can be controlled by kerfing, which is artificially cutting a slot from the outside to the center wood along the bottom side of logs. Checks can trap moisture from rain and snow melt, which will promote wood decay. Kerfing logs on bottom side can prevent checking on upper surface of logs; therefore, it reduces moisture accusation and decay rates of logs during utilization.

4.4 Checking in lumber

Lumber checking is mainly caused by shrinkage differences between the surface and the center of lumber during seasoning or drying. Checking can occur on the ends and the surfaces of green or dried lumber. Many hardwood species, such as oak, beech and sycamore are highly susceptible to checking, whereas sugar maple, yellow birch and ash are intermediate. A wood species with large rays tends to be more susceptible to checking than those species with small rays. Lumber checking causes significant value loss to the hardwood industry, especially to those products processed for furniture, cabinets and millwork. Many lumber checks, especially on rough lumber surfaces, are difficult to locate because they may close in the later stage of drying. Furthermore, some checks often extend longer and deeper than what can be seen by the naked eye; however, the lumber is damaged and the remaining micro-checks can open and split in the future. Excessive reject of checked parts may cause significant volume loss of final products. In general, rapid lumber drying with high temperature promotes checking; therefore, drying hardwood lumber requires a gentle process with lower temperature and higher relative humidity (Rasmussen 1961).

5 Checking Types

Wood checking can be categorized into different types based on their location on wood products. The major types of checks are end checks, surface checks (also known as face checks), internal checks (also known as honeycomb), and micro-checks (hard to see to the naked eye).

5.1 End checks

End checks are cracks at the ends of logs or lumber that occur during storage, seasoning or kiln drying. End checking occurs mostly along wood rays on the ends of logs or boards and appears as cracks on the radius between the pith and bark of logs. End checking is caused by faster loss of moisture content from the ends than from internal sections. It should be remembered that wood dries more rapidly along the grain than across. The shrinkage of wood at the ends forms stress between wood cells that is relieved by developing splits along ray cells. If a log is protected by bark, the end checks will occur mostly on the center (heartwood) of the log ends (Figure 1). When bark is peeled off from the log, the checking will appear mostly on the outside (sapwood) of log ends (Figure 2). The end checking occurring on lumber can go across the whole end section of a board if the board is less than 2 inches, and wide boards are more sensible and create more stress on the weakest part (Figure 3). End checks are usually large cracks that can extend a foot or more from the end to inside of the wood piece. For example, trimming one inch from each end of an eight foot long board due to checking can represent over 2% yield loss. The effect of end checking on lumber yield is therefore significant.

Figure 1 End checks occurred on a bark protected log

Figure 2 End checks occurred on a debarked log

Figure 3 End checks occurred on kiln-dried boards

5.2 Surface checks

Surface checks, also called face checks, refer to the cracks that occur on board surfaces. They may penetrate at varying depths below the surfaces. Similar to end checks, surface checks occur in or along wood rays, but on wood surfaces. They occur when the surface of wood is dried faster than the interior. The shrinkage stress on wood surface exceeds the tensile strength of the wood grain and wood tears itself apart. In some cases, surface checks can appear on the middle of a board and causes value loss on the whole piece (Figure 4). It is estimated that losses caused by surface checking represent about 5% of lumber value after kiln drying (McMillen 1969).

Surface checking can form on lumber at any time during manufacturing, storage and end-use when it is exposed to certain environmental conditions, especially during the drying process. These environmental conditions mainly include hot and cold or drying and humid cycles. In addition, exposure of lumber to ultraviolet and visible light increases the tendency of surface checking caused by photodegradation (Evans et al. 2008). There is a link between changes in cell microstructure caused by photodegradation of lignin and the formation of surface checks in wood exposed outside. Therefore, the most common surface checks occur on decking and siding wood products.

Another problem for manufacturers is the detection of surface checks on wood products. Surface checks often occur on lumber during the early stage of drying and will close at the later stage. The checks become almost invisible on wood surfaces to the naked eye and are very difficult to detect. To find tiny surface checks, a practical method consists in rubbing wax on the surfaces of a wood product, and when it dries, the checks appear in white. With the current development of high technology, surface checks can be detected using a desktop scanner producing high-contrast greyscale images that can be analyzed by software developed to quantify these checks in the images (Christy et al. 2005).

Figure 4 Surface checks in the middle of a board

5.3 Internal checks

Internal checks, also called "honeycomb", are cracks that occur inside of thick boards (>2 inches) during drying or heat treatment process, especially in certain hardwoods with wet pockets or that easily suffer cell collapse during drying (Figure 5). They can also be the result of an extension of surface checks. Internal checks are generally hidden inside of boards and are invisible from the surfaces. To find internal checks, boards have to be cut into sections. This character makes internal checking more difficult to control than surface checking by the quality control process. A computerized image analysis method may require measuring the amount of internal checking in a board. Internal checking often occurs in high-temperature drying or heat-treated wood. The checks are often oriented in the radial direction along the wood rays, since parenchyma ray cells are easier to collapse than other wood cells at high temperature.

Since internal checking is often associated with cell collapse during high-temperature drying, the initiation of internal checking is due to the negative relative pressure during the capillary drying stage. Later stress reversal leads to tension in the cell wall of the internal board, which causes internal checks (Booker 1994). However, no correlation between cell collapse and the internal checking of heat-treated boards has been found in studies; therefore, one may conclude that different mechanisms are involved in internal checking of high-temperature dried and heat-treated wood. Further study showed that the formation of internal checking is positively correlated to board initial moisture content, the wood mass loss, the presence of pith and the fast drying process (Johansson 2005).

Figure 5 Internal checks formed in the middle of a thick board

5.4 Micro-checks

Many checks extend longer than usual observation on rough lumber, and some surface checks are closed after drying (Figure 6). These checks are hidden to the naked eye; however, the lumber is still damaged. If the temperature and moisture content of wood changes, the checks may reopen (Figure 7). When relative humidity goes up, the wood moisture content will increase, and the checks begin to close to a point where they are no longer visible to the naked eye, but can be clearly seen under a microscope. Figure 8 shows a cross section of a wood product with a micro-check. At 50x magnification, the micro-check can be clearly recognized. These checks, invisible to the naked eye, are called micro-checks. After opening and closing several times due to environmental changes, micro-checks will develop into visible checks. The micro-checks are the weakest point of wood products and affect product quality. These checks need to be early detected and eliminated from the products. Micro-checks that become more visible (to the naked eye) after staining at the end of the manufacturing process result in remanufacturing of the pieces. The initial stages of bacterial or fungal infection can also cause some micro-checks (Tremblay and Normand 2011).

Figure 6 A micro-check occurred on a rough surface of a board

Figure 7 A micro-check occurred on a finished wood product

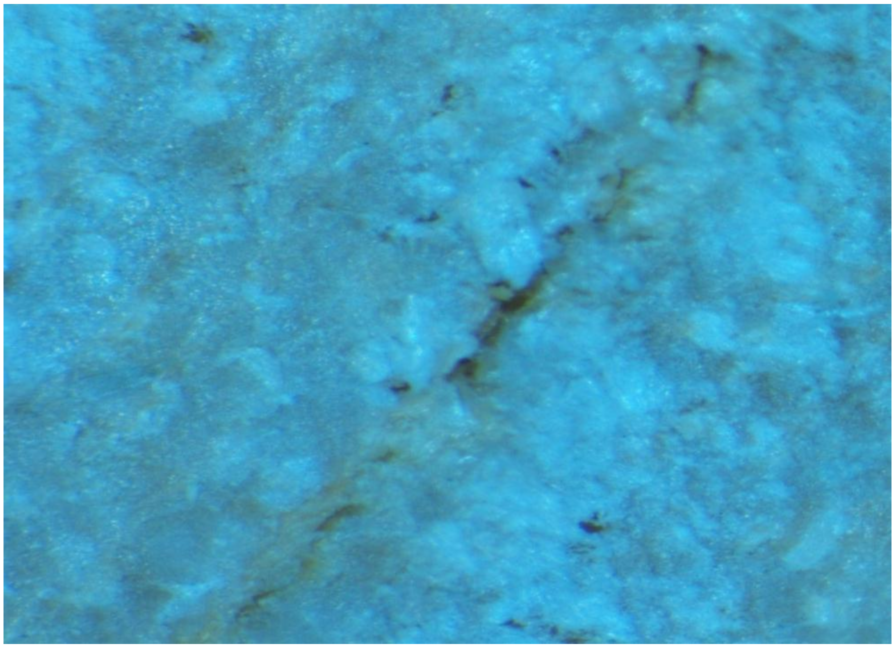

Figure 8 A micro-check observed on a cross section of a board under a microscope

5.5 Mechanical splits

The split is defined as "A lengthwise separation of the wood, due to the tearing apart of wood cells" (NHLA 2007) (Figure 9). In fact, a split cannot be differentiated from checks by appearance only, but it is not a result of seasoning. Mechanical splits are cracks primarily caused by mechanical damages during wood processing (Figure 10). In literature, this type of cracks is often called mechanical damage rather than mechanical splits. The common mechanical damages are caused by harvesting machines as well as debarking and sawing equipment. The metal teeth of machines force into the wood tissue and create squeezing stresses between wood cells in 3D that form cracks along the wood grain to release the pressure (Figure 11). The mechanical damages can cause massive wounds in wood, one or more surface cracks around damaged areas, internal cracks and cell collapse beneath the damaged areas (Figure 12). In addition to cracks, mechanical damages are commonly associated with compression marks and blue stain surrounding the damaged areas. The wounds left on boards caused by press rolls of a log harvesting machine (Figure 13) look more like splits than those wounds caused by end-dogs of a sawing equipment (Figure 14). The harvesters (single- or two-grip harvesters) can also cause mechanical end splits on cut-to-length logs during bucking. Improper operation of harvesters can cause up to 94% of logs with end splits (Eronen et al. 2000).

Figure 9 Splits formed on a finished board

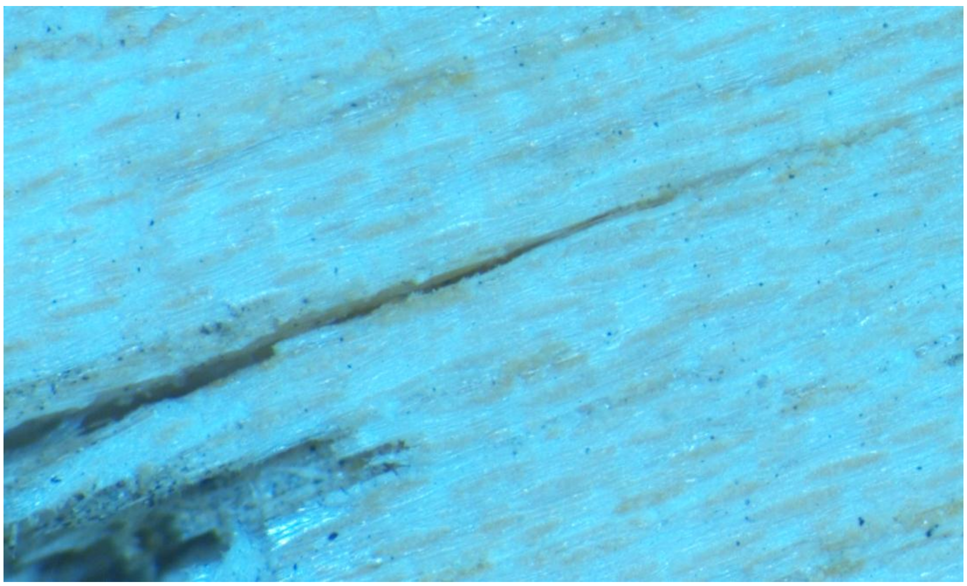

Figure 10 A magnified mechanical split formed at the edge of a wood damaged area

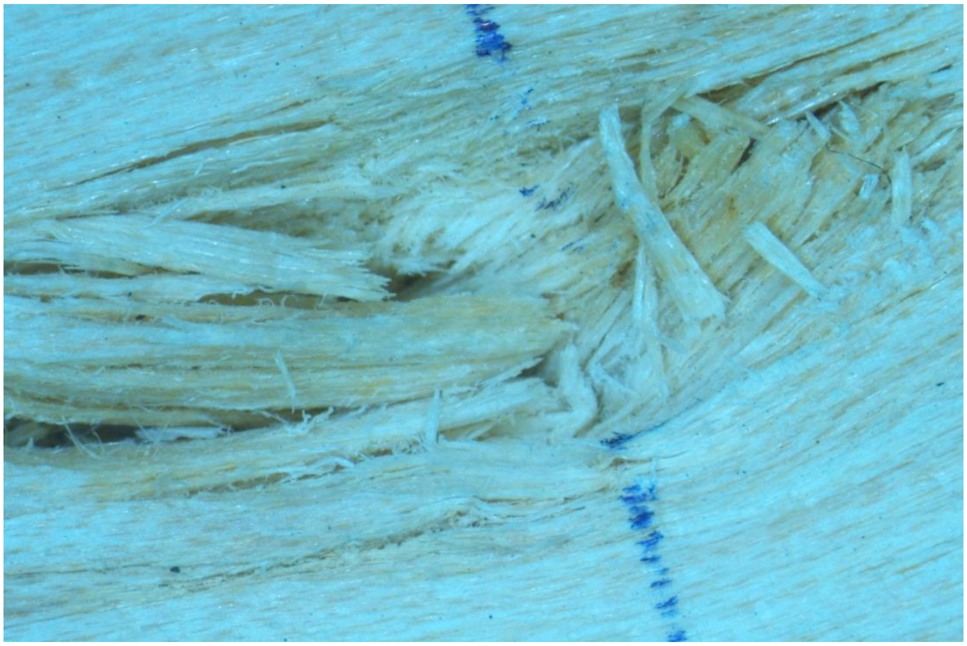

Figure 11 Magnified mechanical damage on wood surface

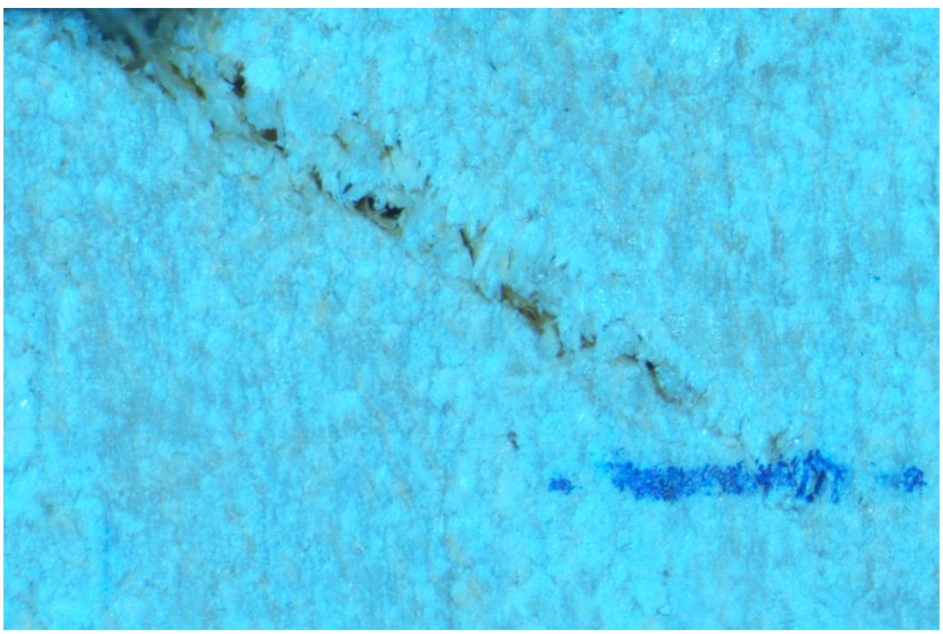

Figure 12 A magnified mechanical split formed at the cross section of a board

Figure 13 Harvester damage on a roughly-sawn sugar maple board

Figure 14 Sawing machine damage on a roughly-sawn sugar maple board

5.6 Shakes

Like splits, shakes are another type of wood cracks often confused with wood checks, which is defined as "A separation along the grain that occurs between the rings of annual growth" (NHLA 2007) (Figure 15). In fact, shakes are longitudinal separations of wood that appear in standing trees caused by growth stresses or by racking in the wind. Shakes can occur in all kinds of hardwoods and conifers, but are most common in hemlocks, true firs, western larch, oaks and sycamores. Because shakes are not caused by seasoning, they cannot be prevented or controlled in sawmills.

Figure 15 Shakes occurred alone with wood grain of a board

6 Checking Control and Prevention

With proper control measures, all kinds of checks can be reduced to a minimal level. These control methods include best practices in harvesting, storage, sawing, drying, chemical coatings, physical methods and control of end-use environmental conditions.

6.1 Protection of logs from checking

Checking damage occurs mostly in logs cut between April and October, therefore winter harvesting of hardwood logs is recommended. In eastern Canada, winter-harvested logs can safely be stored until June of the following year without significant checking (Figure 16). Winter-harvested logs can be stored under snow and bark debris during summer without any checking. Bark damage should be avoided to a minimum during log harvesting, especially during summer operations (Yang and Beauregard 2001)

Logs harvested between April and October should be processed into lumber within 5 weeks after harvesting. Logs that will be stored for more than 5 weeks during spring, summer and fall should be protected with water sprinkling (Yang 2004).

The orientation of green log piles stored in sawmills affects check development. In Quebec, logs should be piled with the ends facing toward northeast-southwest direction in sawmills. In this direction, log ends catch less solar heat, which causes less checking in logs (Yang and Normand 2008).

Applying end coatings to logs is a common practice in sawmills to prevent end-checking (Linares-Hernandez and Wengert 1997) (Figure 17). The coatings can slow down moisture loss from log ends and minimize unequal expansion and contraction due to moisture content changes in logs. The most common coatings consist in paraffin, or wax, a surfactant and water. Based on the moisture transport coefficient measurement, most commercial coatings are effective in reducing moisture loss from wood and little significant statistical differences are found among the commercial log and lumber coatings (Rice 1995). A good coating should slow down moisture loss from log ends to a similar level as from its body. An effective coating must be applied timely to the ends of freshly felled logs to cover the entire surface. A delayed application will reduce the effectiveness of the product. Timing in application of end coating to logs is crucial, it is better within 7 days after felling. Checking is reduced in logs when they are stored in the forest in shaded environments. When it is impossible to immediately end-coat logs after cutting, they should be stored in a forest shaded site. The logs transported to sawmills less than 3 weeks after harvesting should be end-coated immediately upon arrival. It is not necessary to apply coating to the logs that have significantly developed checking in forest (Yang and Normand 2008).

Physical methods are also proposed to prevent checking on small diameter logs or poles. One of these methods involves sending an electric current through the length of the wood piece for a pre-determined period and removing the bark immediately before or after the electric treatment (Marko 1999). It has been claimed that the tendency of wood checking is reduced during subsequent air drying, particularly for poles.

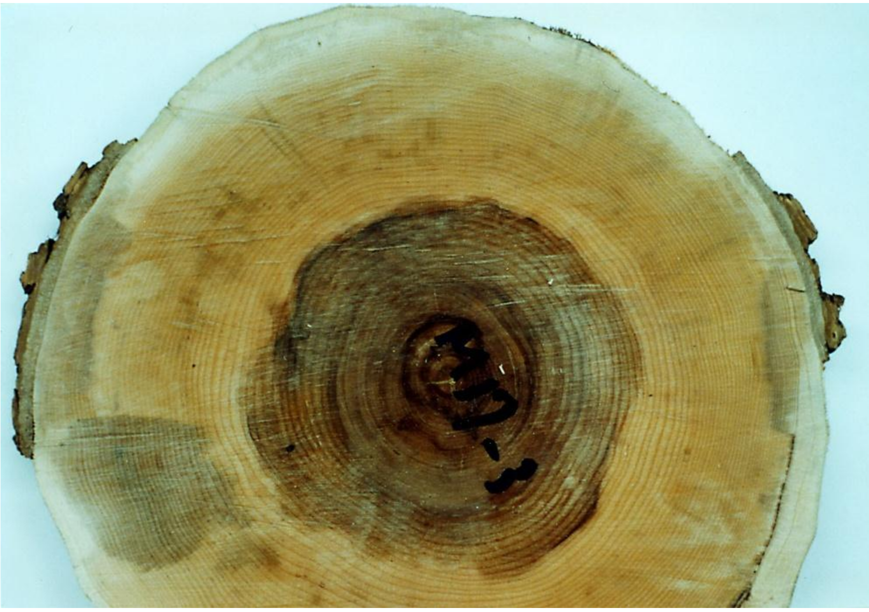

Figure 16 Log protected under snow from checking

Figure 17 Logs protected with silicon (left) and paraffin (right) coatings against checking

6.2 Protection of lumber from checking

A number of technologies have been developed to reduce lumber checking. Fast lumber dying can cause serious checking. The main prevention method is to control drying rate to minimize moisture content differences between surfaces and core wood (Garrahan 2008).

6.2.1 Preventing checks during air drying

To air dry hardwood lumber, it has to be properly stacked in an area with good air movement and protected from direct sunshine. If rain penetration can be prevented, lumber moisture content can reach 15 to 20% without significant checking. To produce high quality lumber by air drying, a shed or pile roof is recommend to protect lumber from excessive exposure to direct sunshine, especially on hot sunny days (Rietz and Page 1971). Airflow or wind is also a factor that affects lumber checking. Lumber piles should be oriented at a slight angle from prevailing winds to reduce drying speed by delaying airflow through the piles. A good practice to minimize sunlight exposure and reduce air flow is to place package ends close together or use some fabric. In general, drying time required for air drying of lumber will depend on wood species and lumber dimensions; one-inch lumber will require 45-65 days of warm weather and two-inch lumber may take more than 90 days in similar conditions.

6.2.2 Preventing checks during kiln drying

To kiln-dry hardwood lumber, it is placed in a dry kiln, where temperature, relative humidity and airflow can be controlled to varying levels, and dried to a moisture content of less than 12%. To produce high quality lumber by kiln drying, it is a common practice to use low temperatures, especially in the initial period of the drying process. It is also common to slow the drying rate of the lumber and the MC differences between shell and core by controlling the ambient relative humidity conditions. To prevent checking, the drying time should be longer than normal schedules.

6.2.3 Preventing lumber surface checks

Resurfacing boards prior to drying is a method to reduce lumber surface checking on certain wood species. Planing both surfaces of rough sawn lumber before drying will decrease the occurrence of checking after drying. The smooth surfaces are more resistant to tension forces caused by drying than rough surfaces. Other benefits of this approach could be reduced drying time, energy consumption, warping and increased drying capacity. However, resurfacing lumber may reduce wood volume by removing approximately 6 to 10% of rough lumber volume. The benefit of this method will depend on different sawmill situations and should be judged by individual sawmills.

6.2.4 Preventing lumber end checks

Lumber end checking can be reduced by applying a commercial end coating to freshly-sawn lumber (Figure 18). The coating slows down the drying speed from lumber ends and reduces stress differences between end and center wood. The coating can be applied with a spray system, roller or brush. Most coatings are white when freshly applied and become transparent after drying. During lumber drying, most of the coatings are vaporized and no film remains on the wood. Application of coatings to whole boards can also reduce surface checking (Rice et al. 1988); however in practice, sawmills usually only apply coatings at the ends of the boards. Lumber should be coated immediately after sawing, especially boards that will be air seasoned outside for a certain time before kiln drying.

Good stickering practices can help reduce end checking. Loads should be piled so that no ends protrude and the outermost stickers are flush with the ends of the lumber. This way, air circulation will be decreased at the ends of the boards and the differential in drying rate versus mid-portions of the boards will be reduced (Garrahan 2008).

Figure 18 Boards protected with paraffin (left) and silicon (right) coatings against checking

6.3 Protection of components from checking

Wood is a natural raw material that exchanges moisture with its surrounding environment. When placed in a dry environment, wood will lose moisture until it reaches equilibrium with its environment. Conversely, when placed in a wet environment, wood will absorb water from air to a consistent level. Repeated absorption and expulsion of water contributes to checking development in components. To control checking on components, storage and end-use environments should use humidification and dehumidification equipment and avoid solar radiation, extreme hot, cold or ventilation conditions. The very low relative humidity is an underestimated cause of checking in many mills. Application of a wax emulsion on components can delay moisture exchange from wood products and therefore reduce the risk of checking on these products (Figure 19). Another simple approach consists in using a plastic sheet to cover the components.

Figure 19 A wood component protected with a wax emulsion against checking

6.4 Protection of composite products from checking

Checking may also occur in composite panels or engineered wood products such as plywood or laminated wood products (Figure 20). In many cases, wood products may be exposed to an extreme low relative humidity environment. In this environment, the moisture content will drop to a very low point and checks will occur in weak spots of the wood products. Checking on composite panels can be minimized with application of proper edge sealant. A good edge sealant can delay moisture movement inside panels, diminish susceptibility of edges to weather changes, and repel rain and water. Storage and end-use environments should be controlled consistently to avoid extreme hot, cold, humid, dry and sunshine conditions.

Figure 20 Checking on a plywood panel

6.5 Protection of end-use products from checking

Wood checking on indoor-used wood products, such as furniture, flooring, millwork and cabinet, can be successfully prevented by controlling indoor temperature, relative humidity and water penetration. For products used outdoor, such as decking and siding materials, the environmental conditions cannot be controlled and practical methods to avoid checking involve application of various coatings on wood products (Grunewalder et al. 2006). The coatings block solar radiation and prevent water penetration. A good quality coating should not only prevent water invasion into the wood, but also have sufficient flexibility to expand and contract with wood upon exposure to hot and cold weather. The coatings can be film-forming paints (Figure 21) or penetrating stains (Figure 22), both types of coatings can be oil or water-based. Film-forming paints prevent both water penetration and water escape, which can lead to blistering and peeling of the paint from the wood. Wood checking is most likely to occur on the areas where paint is peeled (Figure 23). Checking can also occur on wood products protected with penetrating stains when the paint is weathered (Figure 24). The selection of a coating depends on the intended utilization. Most coatings are effective to eliminate or reduce checks on wood products to a certain level for a certain period of time and it can be difficult to choose the best coating for a user. Carefully reading the user's manual and following application instructions of the coating product is suggested. Proper design and installation are also important to prevent water accumulation and checking development.

Figure 21 A wood product protected with a clear film-forming coating

Figure 22 A board protected with a penetrating stain coating

Figure 23 Checking on wood product with a peeled clear film-forming coating

Figure 24 Checking on wood product with a weathered penetrating stain coating

7 References

Booker, R.E. 1994. Internal checking and collapse – which comes first? 4th IUFRO International Conference on Wood Drying, Rotorua, New Zealand. 0-477-01730-4.

Christy, A.G., T. Senden and P.D. Evans. 2005. Automated measurement of checks at wood surfaces. Measurement 37(2): 109-118.

Eronen, J., A. Asikainen, J. Uusitalo and L. Sikanen. 2000. Control of log end checks during bucking with a modified single-grip harvester. Forest Products Journal 50 (4):65-70.

Evans, P.D., K. Urban and M.J.A. Chowdhury. 2008. Surface checking of wood is increased by photodegradation caused by ultraviolet and visible light. Wood Science and Technology 42:251-265.

Garrahan, P. 2008. Drying spruce-pine-fir lumber. FPInnovations – Forintek Division Special Publication SP-527E. Quebec, Canada. pp169.

Grunewalder, J.F., R.R. Brown and R.G. Cox. 2006. Methods for reducing surface checking of a wood product. Patent Application No. WO/2006/066222.

Kolleman, F.P and W.A. Côté, Jr. 1968. Principles of Wood Science and Technology. Berlin-Heidelberg: Springer-Verlag.

Johansson, D. 2005. Strength and colour response of solid wood to heat treatment. Licentiate Thesis. Lulea University of Technology, Division of Wood Science and Technology. Sweden.

Linares-Hernandez, A. and E.M. Wengert. 1997. End Coating Logs to Prevent Stain and Checking. Forest Products Journal 47(4):65-70.

McMillen, J.M. 1969. Accelerated kiln-drying of presurfaced one inch northern red oak. Res. Pap. FPL 122. USDA Forest Serv., Forest Prod. Lab., Madison, WI. 29pp.

Marko, M. 1999. Wood treatment process to prevent splitting and checking during drying. CA Patent No. CA2238353.

NHLA. 2011. Rules for the Measurement & Inspection of Hardwood & Cypress. National Hardwood Lumber Association. Memphis, TN, USA.

NLGA. 2010. Standard Grading Rules for Canadian Lumber. National Lumber Grades Authority. New Westminster, BC, Canada.

Rasmussen, E.F. 1961. Dry kiln operator’s manual. U.S. Dept. Agr. Handbook No. 188. U.S. Forest Service: Forest Products Laboratory, Madison, WI.

Rice, R.W. 1995. Transport coefficients for six log and lumber end coatings. Forest Products Journal 45 (5):64-68.

Rice, R.W., E.M. Wengert and J.G. Schroeder. 1988. The potential for check reduction using surface coatings. Forest Products Journal 38 (10):17-23.

Rietz, R.C. and R.H. Page. 1971. Air drying of lumber: A guide to industry practices. U.S. Dept. Agr. Handbook No. 402. U.S. Forest Service: Forest Products Laboratory, Madison, WI.

Tremblay, C. and D. Normand. 2011. Impacts des changements climatiques (transport) et du Séchage sur la formation de microfissures en surface du bois. FPInnovations-Forintek Report No. 5366. Eastern Region, Quebec, Canada. 40 p.

Wilhelmsen, G. 1969. Protection of wood raw material in Scandinavia. Material und Organismen 4(3):201-229.

Yang, D.Q. and D. Normand. 2008. End coating to prevent checks on hardwood. FPInnovations-Forintek Report No. 5366. Eastern Region, Quebec, Canada. 40 p.

Yang, D.Q. 2004. Prevention of hardwood fungal stain through proper sawmill operations. FPInnovations-Forintek Report No. 3258. Eastern Region, Quebec, Canada. 53 p.

Yang, D.Q. and R. Beauregard. 2001. Check development on jack pine logs in Eastern Canada. Forest Products Journal 51 (10):63-65.