THESIS

NAIL WITHDRAWAL PROPERTIES OF BEETLE-TRANSMITTED BLUE-STAIN FUNGUS IN LODGEPOLE PINE DIMENSIONAL LUMBER

Submitted by

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In partial fulfillment of the requirements

For the Degree of Master of Science

Colorado State University

Fort Collins, Colorado

Fall 2011

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ABSTRACT

NAIL WITHDRAWAL PROPERTIES OF BEETLE-TRANSMITTED BLUE-STAIN FUNGUS IN LODGEPOLE PINE DIMENSIONAL LUMBER

The mountain pine beetle has existed in North American forests for many years to some extent, yet it has reached levels of epidemic proportions is recent years. The recent damage in our forests has been growing at an exponential rate, and there is little that can be done to stop the momentum. The current outbreak has been attributed to two main causes—aggressive wildfire prevention practices in our forests; and warmer winters that no longer reach the lower temperatures which used to kill the beetles seasonally. These two factors have allowed some forests to generate mountain pine beetle infestation rates higher than 50 percent.

While there is little that can be done to stop the beetle, the wood can be harvested for commercial purposes after the attack. When the mountain pine beetle enters a tree, a blue-stain fungus is subsequently inoculated into the sapwood. It is the fungus that ultimately kills the tree by preventing water translocation through the cells in the sapwood. A few studies have found that if the tree is harvested within a few years of the attack, the wood produced from these trees maintains most mechanical properties. However, the body of knowledge on blue-stained wood is still quite limited and many researchers agree more studies need to be conducted.

Most wood grading rules do not degrade wood for the presence of blue-stain, which would lead one to believe that with the massive potential supply of blue-stained lumber in our forests, it would be consumed at a high rate. It has been found, however that blue-stained wood is failing to generate demand, due in part to negative consumer perception of the mechanical properties of the wood.

This study was aimed to refute the negative perception of blue-stained wood by performing a comparative study of the nail withdrawal properties of blue-stained and clear lodgepole pine dimensional lumber. This study harvested 10 blue-stained and 10 clear lodgepole pine trees from Summit County, Colorado. The trees were then milled, planed and cut into small blocks. Each block was tested for moisture content, specific gravity, face withdrawal and cross section withdrawal. The study found that on average, the blue-stained samples had slightly lower withdrawal resistance when compared with clear wood, for cross section withdrawal. On the other hand, the blue-stained sample generated a slightly higher average resistance than the clear wood for face withdrawal, and that when controlled for moisture content; the blue-stained samples yielded approximately 40 lbs more resistance than the clear wood samples, or a 7% increase. The difference in means being so minimal, it was concluded that there was no statistical or practical difference in nail withdrawal properties between blue-stained or clear wood samples using the cross section withdrawal test. It was also concluded that presence of blue-stain in lodgepole pine dimensional lumber could increase face withdrawal resistance.

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CHAPTER ONE

Introduction

The earth's population currently stands at an estimated six and a half billion, nearly a two and a half fold increase from fifty years prior. This fact has introduced potential problems for the future in regards to consumption of goods and natural resources. In recent years we have realized substantial increases in utilization of limited raw materials to produce goods to meet the needs of the earth's population (Bowyer, Shmulsky & Haygreen, 2007). As a result, timber harvests will increase by forty-one percent over the next fifty years to meet the growing demand for wood products (Haynes, Adams & Mills, 1995). Because raw materials are limited in supply, it will become increasingly important in the decades ahead to focus more attention on the utilization of renewable sources with sustainable management plans.

In recent years North America's structural framing lumber resources have experienced drastic changes due to an escalating pine beetle epidemic, which leaves acres of dead, blue-stained trees standing in our forests. Looking at Colorado specifically, the Colorado Division of Forestry (2010) estimated that Mountain Pine Beetle inhabits 878,000 acres of the Front Range forests, and that the outbreak appears to be declining, only because of the lack of available trees (see Figure 1). Most of the lodgepole pine trees that have survived this surge are younger trees, that have sprouted after recent timber harvests.

2010 Mountain Pine Beetle Activity
by Host Species

Figure 1. Mountain Pine Beetle infested area in the Front Range in 2010[1]

It has reached the point that some estimates are predicting that over 90% of mature lodgepole pine populations in some Colorado forests will succumb to beetle-attack in the next few years (Berwyn, 2006). Two causes for this growth are (1) modern forest management strategies and (2) aggressive wildfire fighting practices. Combined, these practices have lead to a twenty-eight percent increase in the number of old, vulnerable trees in North American forests since the early 1900's (Taylor and Carroll, n.d.). As a result, there is a rapidly increasing number of beetle-attacked trees in these areas, which leaves forests with vast amounts of dead, standing trees. The image in Figure 2 depicts an area where trees have been affected by beetle-attack. The reddish-orange trees are

[1] Adapted from, Colorado Division of Forestry. (2010). Report on the health of Colorado's forests. *Colorado Department of Natural Resources*, 6.

characteristic of trees that have been killed by beetles.

Figure 2. Trees in Summit County infected with the Mountain Pine Beetle[2]

Statement of Problem

Upon attack, the Mountain Pine Beetle (see Figure 3) introduces blue-stain fungi into the sapwood of victim trees. Historically, non-stained lumber has been used for structural framing in homes and buildings. Given the current beetle-killed pine situation, there are acres of dead, blue-stained trees in our forests that could be utilized to meet the demands of the building industry. Don Adams, general manager of a lumber mill in southern Wyoming, no longer in operation, estimated that current timber deliveries are now yielding forty to ninety percent blue-stained logs, and that mills in the Rocky Mountain region no longer receive pure, non-stained deliveries (personal communication, September 25, 2007).

2 Photograph taken by Michael Mizell

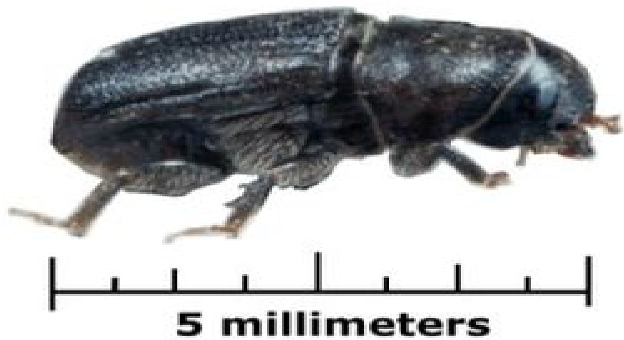

Figure 3. Photograph of the Mountain Pine Beetle[3]

Interestingly, while blue-stained structural lumber is not degraded by grading rules such as the Western Lumber Grading Rules (1988), customer related issues with value and performance are the main obstacles regarding low consumption rates and value degradation. Some lumber suppliers have reached the point of refusing blue-stain lumber to evade this issue altogether (Goldie, n.d.).

Levi and Dietrich (1976) conducted a survey aimed at more clearly understanding the reduced value obtained from blue-stained lumber. The most significant finding was that the monetary value of blue-stained wood in some regions is lower while it is more expensive to produce. They establish that many producers found blue-stained wood increases required air-drying time; and kiln-drying green and blue-stained wood together is not possible, because they require differing drying schedules. Finally, it is stated that many consumers confuse the blue-stain with mold, further reducing demand for the product (Byrne, Stonestreet, & Peter, 2005).

3 Figure provided by, Wikipedia. (n.d.) Retrieved September 2007, from http://en.wikipedia.org/wiki/Special: Search?search=&fulltext=Search.

Although the supply of blue-stained dimensional lumber could be abundant, negative consumer perception about the stain pushes the market value below that of clear pine. In 2009 when Big Horn Lumber Co. was still in operation, general manager, Dan Colgan stated that lumber produced in the 2" form in the past yielded the same value as non-stained lumber, however consumer preference limited consumption of this product which would likely lower its value in the long run, much in the same way 1" finish lumber has been devalued—while one thousand board feet of the 1" non-stained lumber would cost $500, blue stain would yield $375 - $400 (personal communication, March 5th, 2009, Dan Colgan).

As a response to consumer perception of the value and performance of blue-stained lumber, few studies (Lum, 2003; Lum, Byrne & Casilla, 2006; Lam, Jianzhon & Zaturecky, 2006; Levi & Dietrich, 1976; McLain & Ifju, 1982; Sinclair, 1971) have focused on determining the effects of the blue-stain on lumber properties. Although the above studies have reported little to no negative factors regarding the stain on mechanical properties, researchers agree further investigation on this topic is necessary (Byrne et al, 2005).

With thousands of acres of pine trees succumbing to Mountain Pine Beetle attacks, there is an abnormally large supply of pine trees in our forests that could be salvaged for use in the construction industry. If these beetle-killed trees are not harvested in the immediate future, their moisture content levels could fall below the fiber saturation point. When this happens, significant water-loss is experienced in the cell walls which creates tangential shrinkage and checking in the sap and heartwood, and could result in the trees becoming susceptible to fire and becoming unharvestable (Bowyer, Shmulsky & Haygreen, 2007).

While “patch cutting” or clear cutting can be a sustainable, healthy way to manage our forests, some forest are managed with preservationist policies which produces old, vulnerable trees prone to disease and fire, especially in beetle-inhabited areas. These types of management plans can prove harmful to forests and the economy, and can result in massive forest fires and depletion of once-usable natural resources. (personal communication, Dan Colgan, March 5, 2009).

This study is intended to strengthen the blue-stained wood body of knowledge by determining differences, if any between blue-stained and clear wood nail withdrawal properties in dimensional lumber. While blue-stained finish lumber has been viewed as desirable to some, consumers tend to be hesitant about utilizing blue-stained lumber for structural purposes, for fear that it may not be as structurally sound and clear wood. The results are aimed at eliminating misperceptions about the integrity of dimensional lumber infected with blue-stain fungi, and to persuade consumers to purchase blue-stained structural lumber without reservations.

Discussion of Problem

When lumber is sold with obvious visible flaws, the effects of those defects should be known and disseminated to consumers. Because such limited research has been performed on blue-stained wood, effects of the fungi on some lumber properties are still largely unknown. This becomes a dilemma for consumers because there is little data to refute negative perceptions about the blue-stain. Comprehensive information about the effects of blue-stain on lumber should be available to consumers utilizing these products so that quality decisions and proper lumber selection is made.

Increased consumption of blue-stained lumber will result in a greater percentage of beetle-killed trees being harvested. This will (1) reduce fuel loads in our forests, (2) reduce consumption of healthy trees in other areas that have not been affected by disease and (3) reduce the deforestation trends realized worldwide that result in massive releases of carbon into the atmosphere, loss of critical habitat and degradation of watersheds.

Research Question

In order to address low consumption rates due to consumer perception about blue-stained lumber, this study was designed and conducted to determine if beetle-transmitted blue-stain fungus affects nail withdrawal properties of lodgepole pine dimensional lumber.

Hypothesis

The hypothesis of this research was that with the moisture content and specific gravity variables equalized between samples, the presence of blue-stain fungi would not negatively affect withdrawal resistance in lodgepole pine dimensional lumber.

Delimitations

Nail withdrawal resistance depends heavily on nail type. Stern (1949) found that annularly grooved low-carbon-steel nails offer a larger withdrawal resistance than spirally grooved low-carbon steel nails, with both showing higher withdrawal resistance than plain shank nails. The proposed research deals solely with the withdrawal properties of power-actuated sixteen-penny smooth wire nails—the most commonly used nail for adhering light structural members in the framing industry. Therefore this study will not account for nails altered for holding ability.

This study will examine the impact of blue-stain on the nail withdrawal resistance of lodgepole pine dimensional lumber. Westman and McAdoo (1969) found that withdrawal resistances vary between woods species. This study concluded that Western Hemlock had significantly higher withdrawal resistance than Douglas Fir. While it would be possible to find species that yield greater withdrawal properties for light framing lumber, the research will be limited to lodgepole pine because it generates considerable amounts of blue-stained wood due to its extreme susceptibility to pine beetles.

Lodgepole pine is used in many construction applications such as: telephone poles, fencing, decking, house logs, dimensional lumber, furniture and railing, tongue and groove paneling, and structural plywood (Colorado State Forest Service, 2006). For the purposes of this study, dimensional lumber will be the only tested application. While the findings may be roughly transferable, they do not suffice as implications for other applications and fasteners.

Often times equilibrium moisture content[4] is a level that is not reached until structural members have been set and sheathed inside a building. Sentf (1971) found that some species of wood have different withdrawal properties as moisture content varies, which this test will not analyze.

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[4] The moisture content that wood will reach in sustained periods of relative humidity and constant temperature (Wikipedia, n.d.)

Finally, it is known that corrosion of the nail, over time will increase withdrawal resistance in certain woods (Sentf, 1971). This study will only test immediate nail withdrawal and will not give an accurate prediction of time-related withdrawal resistance.

CHAPTER TWO

Review of Literature

This Review of Literature concentrates on four main topics of interest. First, the extent of the current beetle-killed pine epidemic is documented and the nature of the Mountain Pine Beetle and its relation to blue-stain fungi is explained. Secondly, grading rules are discussed as they pertain to stained lumber. Thirdly, a review of current research performed on the effects of blue-stained lumber for various applications utilized in the construction industry is presented. Finally an overview of nails and their relationship to withdrawal resistance is given.

Mountain Pine Beetle

The Mountain Pine Beetle introduces fungi into sapwood upon attack of newly invaded trees. The Mountain Pine Beetle forms a symbiotic relationship with fungi such as *Ceratocystis* and *Europhium* which are inoculated into victim trees as the beetles bore through the phloem.[5] Damage to the sapwood would not be as serious if these fungi were not incorporated during the attack. These fungi produce obvious visible staining in the

[5] Tissue located between the outer bark and cambium which transports glucose and starch made during photosynthesis (Wikipedia, n.d.)

sapwood (see figure 4) of trees and create noticeable visual defects in lumber used for construction purposes (Chow, 2007).

Figure 4. Stained sapwood produced by blue-stain fungi[6]

Historically Mountain Pine Beetle (*Dendroctonus ponderosae*) infestations have infected forests across North America ranging from the Pacific Coast east to South Dakota and from western Canada, south into northwestern Mexico (Amman, McGregor & Dolph, 1990) (see Figure 5).

6 Photograph taken by Michael Mizell.

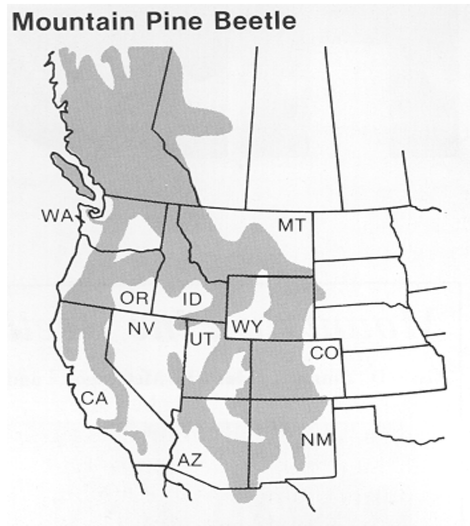

Figure 5. Current Mountain Pine Beetle Region[7]

Although these outbreaks occur frequently, there has never been an invasion of the magnitude faced today. Researchers (Byrne et al, 2005: Taylor & Carroll, n.d.) suggest this phenomenon is due to the ways in which forests are managed and the problem of the earth's increasing temperature. For example, modern firefighting tactics have created forests that are (1) unable to cleanse themselves, thereby disallowing them to eradicate invaders such as the Mountain Pine Beetle, and (2) comprised of older fire-prone trees that are prime habitats of the Mountain Pine Beetle (Taylor & Carroll, n.d.).

The problem of Mountain Pine Beetle vulnerable forests is further exacerbated by the effects of mild winters experienced in recent years. The current attacks have been due in part to many consecutive years of warm winters that do not reach cold enough temperatures to kill the beetle. It is generally believed that sustained periods of negative forty degrees Fahrenheit are required to reach that point (Chow, 2007). Logan, Regniere and Powel (2003) performed a study assessing the relationship between global warming

[7] Figure provided by, Amman, Gene D, Mark D. McGregor, and Robert E. Dolph Jr. (1990). Mountain Pine Beetle. *Forest Insect and Disease Leaflet*, 2, 1-6.

and forest pest dynamics. They state that insects and pathogens are now the leading cause for disturbances in our forests and affect an area nearly fifty times greater than fires. It is found that many pest species have co-evolved relationships within forests over time that have limited long term effects. However, increasing desirable climate conditions for pests such as the Mountain Pine Beetle will likely result in disastrous consequences in the near future. Finally, their results foresee insect outbreaks intensifying as the climate continues to warm.

Physiology

The Mountain Pine Beetle infests softwood species, especially lodgepole pine (*pinus contorta*), due to its easily penetrable outerbark. Mountain Pine Beetles bore through the bark into the phloem where they spend much of their life. Egg galleries are constructed within the phloem where the larvae are left to develop on their own. The larvae then feed in the phloem before entering pupation[8]. After pupation, the Mountain Pine Beetle is fully developed and exits the tree. Male Mountain Pine Beetles are attracted to new trees through both pheromones excreted by female beetles, and the ethanol by-product of decaying trees, which results in colossal attacks on newly penetrated tree (Chow, 2007).

The female beetles construct straight, vertical egg galleries in the phloem, and rarely intrude on the sapwood. The egg galleries range from four to forty-eight inches long, averaging about ten inches (see Figure 6). The females produce white eggs, which are deposited along the sides of the galleries usually in the summer months. The eggs

8 Motionless non-eating stage where beetles develop into the adult stage (Wikipedia, n.d.)

hatch after ten to fourteen days. Females that survive the winter may lay eggs in the early spring and reemerge and attack additional trees (Amman et al, 1990).

Figure 6. Egg galleries produced by the Mountain Pine Beetle[9]

The trees attempt to defend and repair damage by increasing their resin secretion to entrance and exit holes, but by this point the pine has usually suffered such a massive attack there is little chance for recovery (Lemaster, Troxell & Sampson, 1983).

Blue-stain

It is the fungi carried by the Mountain Pine Beetle that cause the blue-stain in sapwood. The hyphae[10] from the fungi predominantly grow in the rays[11] of a tree and attack cell lumens[12]. The hyphae typically pass from cell to cell through pits[13] even

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[9] Photograph taken by Michael Mizell

[10] The long, branching filamentous cell of a fungus, which is the main mode of vegetative growth (Wikipedia, n.d.)

[11] Cells that run laterally from the pith to the outer bark (Wikipedia, n.d.)

though they can breach cell walls. The establishment of these fungi prevents water translocation,[14] resulting in lower moisture content and weakening of the tree's defense mechanisms (Levi & Dietrich, 1976). These factors, coupled with the girdling effect caused by massive numbers of beetles inhabiting the phloem, soon lead to the starvation and death of the tree. Death can occur as quickly as two weeks after the attack. By the time the characteristics of infection can be detected nearly, one hundred percent of the sapwood could be stained (Byrne et al, 2005).

Low Moisture Content

A secondary effect of blue-stain fungi on beetle-killed wood is extreme dryness. It has been found that healthy trees typically have sapwood moisture content between eighty-five percent to one hundred sixty-five percent, while beetle-killed trees infested for one year have sapwood moisture content as low as sixteen percent. This may cause structural problems in lumber such as bending, moisture absorbsion, linear expansion, screw withdrawal and bondability in lumber (Reid, 1961). In addition, it could cause the moisture content of the tree to fall below the fiber saturation point, resulting in differential shrinkage and checking before it is harvested. Should this occur, the tree would no longer become harvestable for dimensio lumber use due to extreme random cracking of the heart and sapwood. (Bowyer, Shmulsky & Haygreen, 2007).

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[12] Interior canal in cell wall (Wikipedia, n.d.)

[13] Elements that bond adjacent cells (Wikipedia, n.d.)

[14] The transportation of dissolved substances throughout the tree (Wikipedia, n.d.)

Shelf Life

Fahey, Snellgrove and Plank (1986) find that considerable property losses of beetle-killed trees are realized between one and three years after the attack of the beetle. This shelf life[15] is longer than that of other insect damaged trees because the Mountain Pine Beetle bores through the bark and does not penetrate through the sapwood. While some insects may bore through the entire tree essentially eliminating any chance of harvesting, the Mountain Pine Beetle leaves the sapwood and heartwood relatively untouched (Byrne et. al., 2005). It is important to note that while the tree is left standing dead after the attack, it is only harvestable for construction purposes within the next few years (Fahey et. Al. 1986).

Grading

Lumber is routinely graded using individual grading agencies that typically determine that the blue-stain is simply a visual defect. Lumber grading is determined by agencies that have been accredited through the American Lumber Standard Committee (ALSC). The ALSC is a non-profit organization incorporated in the State of Maryland that received consent from the Voluntary Product Standard system of the Department of Commerce to carry out lumber standards. The ALSC is comprised of manufacturers, distributors, users, and consumers of lumber; and it serves as the standing committee for the American Softwood Lumber Standard (American Lumber Standards Committee, Inc., n.d.).

Since the ALSC is responsible for the formulation of lumber grading rules spanning the entire United States, it has allowed smaller accredited agencies to develop

[15] The time between harvest and the initiation of beetle attack (Sinclair, 1979)

grading rules that pertain to specific geographical niches, such as the Western Wood Products Association (WWPA). The WWPA has established fourteen criteria for determining softwood lumber grade (Western Lumber Grading Rules, 1988). One of the criteria deals directly with stained wood. According to this criterion, "Stained sapwood. Firm heart stains or firm red heart…[are] not limited" (Western Lumber Grading Rules, 1988, p. 87). Therefore dimensional lumber with any amount of stain is considered suitable for light framing.

Tested Construction Applications

Even though lumber grading rules such as the Western Lumber Grading Rules do not degrade lumber due to stain, various studies have been performed to establish the effects of blue-stain fungi to address consumers' negative perceptions of the stain. Many of these studies have been summarized in a table produced by Forintek Canada Corporation (2003). (see Table 1)

Table 1
Summary of tests conducted on blue-stained lumber[16]

Tested Properties	Results	Implications
Stiffness and Breaking Strength	No significant difference.	These are the most important strength properties for structural applications. Bluestained wood is as strong and stiff as non-bluestained wood.
Impact Resistance (Toughness)	Slightly lower (5%) impact resistance for bluestain.1	Toughness is not a critical strength property for most end-uses of wood but is one of the first properties affected by biological agents.
Truss Plate Grip Capacity	Measurable (6%) increase in ultimate grip capacity but similar slip for blustained wood as for nonstained wood.	Good plate grip capacity is critical for the design and manufacture of trusses. The measured increase is not of practical significance for truss design
Dimensional Stability and Checking (in Repeated Wetting / Drying)	Bluestained wood was significantly less prone to warping when tested in our simulation of outdoor exposure. Cracks were significantly smaller in bluestained wood.	Bluestained wood seems to develop micro-cracks (hairline cracks). This may have implications for kiln-drying practices, as well as potential benefit for the appearance and performance of wood in outdoor use. True outdoor testing is needed to clarify the implications.
Permeability and Treatability with Preservatives	Bluestained sapwood wets more readily with water. The heartwood resistance to treatment is unchanged.	Bluestained sapwood is more easily treated with wood preservatives and fire retardants.
Glue Joint Integrity	No difference between bluestained and non-bluestained wood.	No changes required for use of either structural or non-structural adhesives with bluestained wood.
Finishes for Masking Bluestain	Best masking of bluestain for furniture-grade products is achieved with stains, toners, or glazes containing blue, red, or charcoal tints.	Furniture manufacturers could use combinations of these tints to reduce stain/non-stain color contrast without making the product too dark.
Finishes for Enhancing Bluestain	Clear finishes are best at enhancing or highlighting the bluestain.	Some people find the bluestain visually appealing (see FAQ #8).
Finish Adhesion	No difference between bluestained and non-bluestained wood.	No changes required for use of stains, toners, and glazes.

16 Adapted from Forintek Canada Corp. (2003). Properties of lumber with beetle-transmitted bluestain. *Forintek Canada Corp., Western Division*, Vancouver, B.C. Wood Protection Bulletin, Retrieved September 2, 2007, from http://www.forintek.ca/public/pdf/ woodprotbulltn.pdf.

Table 1 summarizes the most important studies conducted on blue-stain properties over the last few years. As is evident in this table, little to no significant differences between most blue-stained wood and clear wood has been found. The research summarized in this table shows no decrease in strength or stiffness in structural lumber. One study actually presented a six percent increase in grip capacity of engineered truss plates with blue-stained wood. Additionally it had been found that blue-stain lessens susceptibility to lumber warping, which is a significant benefit to geographical locations with high annual rainfall and humidity. Furthermore, presence of blue-stain has also shown to increase permeability, which has positive implications for preservative treated applications such as pressure-treated lumber. In contrast to the positive characteristics, most of the current research performed on blue-stain has given one significant negative effect on wood—the visible blue-stain. However, the presence of blue-stain has been found to enhance value in some applications such as cabinetry and finish lumber (Byrne et al, 2005). Based on the studies summarized by the Forintek Canada Corporation (2003) there is no empirical data to support degrading blue-stained lumber for decreased mechanical properties.

Nails

Nails are the most common form of mechanical fastener used in the construction industry to adhere wood members. Nails are ideally suited for this purpose because they add significant strength and stability to joints with minimal penetrative effort. Nails may yield differing withdrawal resistances depending on how it is manufactured. Commonly manufactured nails include common wire nails, smooth box nails, cement coated nails, and helically and annularly threaded nails (Soltis, n.d.).

Withdrawal Resistance

The withdrawal resistance of a nail is heavily influenced by (1) the physical properties of wood members such as specific gravity and moisture content, (2) characteristics of the shaft of the nail and (3) the depth of penetration. Although softwood typically embodies lower specific gravity than hardwood, it is often more beneficial for structural purposes because it has a lower tendency to cleave. Therefore softwood species offer opportunities for increasing the length and diameter of the nailing element, and number of penetrations into the specimen to compensate for its lower density (Soltis, n.d.).

The following formula, p = 6900 G5/2D is commonly used for estimating nail withdrawal resistance loads for nails driven into the face or cross section of wood with common wire nails where: p represents the ultimate load per lineal inch of penetration in the member holding the nail point; G is the specific gravity of the wood based on weight and volume when oven dry; and D is the diameter of the nail in inches. Lodgepole pine may yield a specific gravity of .41.[17] Therefore the relative nail load of lodgepole pine is 830. The load per inch of penetration immediately after driving may be obtained by multiplying this nail-withdrawal factor by the diameter, D. As a result, the value of 830 multiplied by the diameter value of a sixteen-penny common nail (0.162-inch diameter) will result in the approximate nail withdrawal resistance load (see Table 2). Thusly, by

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[17] The specific gravity of lodgepole pine typically falls inside the range of .26 and .55 (Bowyer, Shmulsky & Haygreen, 2007)

multiplying 830 by 0.162, a value of 134.46 pounds per inch of penetration will represent the estimated resistance load per inch of penetration. It is stated that this equation is general and cannot provide precise predictions for determining withdrawal resistance, because there may be other uncontrolled factors that could affect empirical studies (United States Department of Agriculture Forest Service, 1965)

Summary

Even though Mountain Pine Beetle infestations have occurred in the forests of North America in the past, research on the effects of the blue-stained lumber is limited. This is partially due to the fact that invasions of this magnitude have not been realized until recently. Blue-stained lumber is a resource that may be abundant for a short period of time, and if not exploited, it could result in vast amounts for forests becoming unharvestable. This paper intends to address a partial gap in the blue-stained lumber research, by providing empirical evidence of blue-stained lumber mechanical properties. It is hoped that the results from this study will help reduce consumers' negative assumptions about blue-stained lumber.

CHAPTER THREE

Methodology

The purpose of this study was to determine if beetle-transmitted blue-stain fungi affect nail withdrawal properties of lodgepole pine dimensional lumber. This study followed (1) ASTM D 1761 and ASTM D 2395 guidelines produced by the American Society for Testing and Materials (ASTM)[18], (2) processes developed in the Materials and Testing Laboratory at Colorado State University by Dr. Charles W. Smith, and (3) processes developed specifically for this study.

Sample

The sample was supplied by twenty logs harvested from Summit County, Colorado. Ten beetle-killed trees and ten clear trees were selected for the study. The trees were cut from a one hundred-acre plot of land that was contracted out to Morgan Timber Products through the USDA Forest Service. The trees were felled with a harvester that cut, delimbed and segmented each round into rough eight-foot logs.

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[18] ASTM has developed technical standards for materials, products, systems, and services for over one hundred years. It is an internationally recognized institution that addresses standardization needs worldwide and throughout diverse industries (Annual Book of ASTM Standards, 1994).

Figure 7. Harvester cutting and delimbing a tree[19]

The logs were transported to a local mill where they were rough-cut into 2x4's. Each log yielded between two and three 2x4's. After the 2x4's were cut into rough dimensions they were stickered[20] for four weeks in a temperature controlled room at a relative humidity of 35%. The specimens were subsequently planed, cut into six inch blocks and transferred to the same temperature and humidity controlled room for five additional weeks to reach the equilibrium moisture content. In this condition the specimens reached a relative moisture content below nineteen percent[21] before testing proceeded.

19 Photograph taken by Michael Mizell

20 Stacked on shims to allow for consistent air flow on each side of the two by four

21 Nineteen percent moisture content can generally be attained by open air drying without the necessity of kiln drying; and is the standard for dry lumber currently accepted by Federal Housing Authority, numerous building codes and grading rules (Hickman, n.d.)

Figure 8. Two by Fours stickered in temperature and humidity controlled room.[22]

Specific Gravity

There is considerable natural variability in wood, which is influenced by specific gravity[23]. Specific gravity can vary significantly between and within trees. Specific gravity alters the mechanical properties of wood (Wang & Wang, 1999) and consequently may have an effect on nail withdrawal resistance. The lodgepole pine specimens cut for this study should exhibit specific gravities ranging between .26 and .55 (Bowyer, Shmulsky & Haygreen, 2007), but could possibly have three factors that affect that range—decay in the blue-stained specimens, compression wood[24] and juvenile wood[25]. Therefore, specific gravity was tested for each two by four following ASTM D 2395 guidelines before use.

22 Photograph taken by Michael Mizell

23 A ratio that compares the density of wood to water (Wikipedia, n.d.)

24 Cambium in the affected part of the trunk is more active on one side due to increased mechanical loading (wind and snow), leading to thicker growth rings (Wikipedia, n.d.)

25 Secondary xylem found within the first five to ten growth increments (Bowyer et al, 2007)

ASTM D 2395—Specific Gravity

The following procedure was utilized to test for specific gravity:

5.2 Measurements—The dimensions of test specimens shall be measured to a precision of $\pm$ 0.3% or less, and the weight shall be determined to a precision of $\pm$ 0.2% or less. Where drying of specimens is required, this shall be done in an oven maintained at 103 $\pm$ 2˚C. (For most panel materials and wood specimens 1 in. (25mm) in length parallel to grain, drying for 48 h in an oven having good air circulation and exchange will be sufficient to reach constant weight.) (p. 361).

7.1 Measurement—Measure the length (L), width (w), and thickness (t) of the specimen in accordance with 5.2 in a sufficient number of places to ensure an accurate indication of volume…in larger specimens the number of measurements will depend on the uniformity of the specimen, but at least three measurement of each dimension will be required (p. 361).

7.2 Weight—Determine the weight (W) of the specimen at the time of observation or test in accordance with 5.2 (p. 361).

7.3 Moisture Content—Determine the moisture content (M) of the specimen to permit description of the basis on which the specific gravity is computed. (p. 361).

7.3.3 Structural Elements—In full-sized members, determine the moisture content from a segment cut from the member. It shall be of full cross-sectional dimension and 1 in. (25 mm) in length (parallel to grain), and shall be selected from a representative area of the member. To avoid the effects of end drying, cut the specimen at least 18 in. (457 mm) in from the end of the member (p. 361).

8.2 Specific Gravity—Calculate the specific gravity as follows:

$$sp\ gr = KW/[1+(M/1000)]Lwt$$

where:
W = weight of specimen,
M = moisture content of sample, %,
W/[1+(M/100)] = calculated oven-dry weight of specimen,
L = length of specimen,
w = width of specimen,
t = thickness of specimen, and
K = 27.68 when weight is in lbs and volume is in $in.^3$ (p. 361).

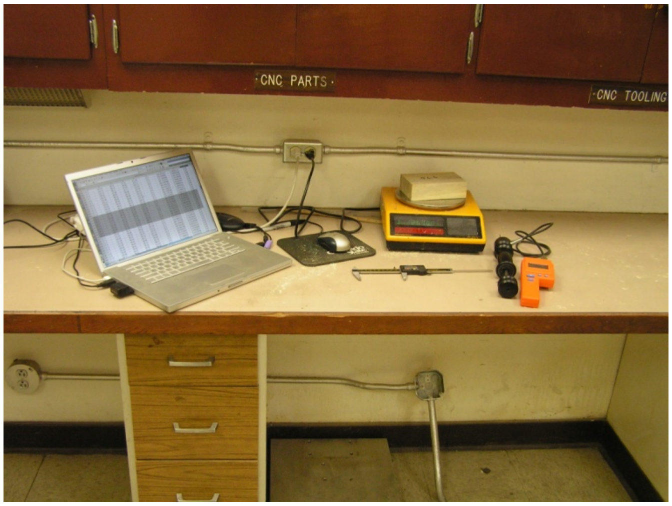

Figure 9. Workstation used to determine moisture content and specific gravity of each block, including calipers, scale, and moisture content reader[26]

American Society for Testing and Materials D 1761—Withdrawal Test

According to ASTM D 1761 (1994) withdrawal is “the resistance of a species of wood or wood-base material to direct withdrawal of nails, staples or screws” (p. 280). ASTM has developed these principles in order to measure the “ability of wood to hold an adjoining object by means of fasteners” (p. 280). It is stated that physical and mechanical properties of wood such as “size, shape and surface condition of fasteners, speed of withdrawal, physical changes to wood or fasteners between time of driving and time of withdrawals, orientation of fiber axis, and occurrence and nature of prebored lead holes” (p. 280-81) may affect withdrawal resistance.

With this in mind, all samples were produced to achieve the least variability between specimens. All specimens were planed to the same relative shape and smoothness in the surface condition.

[26] Photograph taken by Michael Mizell

Summary of Test Method

The nail resistance test followed instructions for nail withdrawal ASTM D 1761 section three, which is described as:

> 3.1 Specimens consist of prisms[27] of wood or wood-base products, with nails, staples or screws driven at right angles to one or more faces. The fasteners are withdrawn at a uniform rate of speed by means of a testing machine, and the maximum load is recorded. Supplementary physical properties of the wood or wood-base product are also determined (p. 280).

Apparatus

The testing machine conformed to ASTM D 1761 section five, which requires the testing machine to be capable of operating at a constant rate of motion for withdrawal. It had an accuracy of plus or minus one percent when calibrated in accordance to Practices E4[28]. The gripping device was shaped to fit the base of the fastener head so that true axial loading is achieved. A clamping assembly was necessary to secure the specimen to one platen[29] of the machine.

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[27] Three-dimensional specimens (Annual Book of ASTM Standards, 1994)

[28] Practices for Force Verification of Testing Machines found in the *Annual Book of ASTM Standards*, Vol 03.01 (Annual Book of ASTM Standards, 1994)

[29] Securing mechanism (Wikipedia, n.d.)

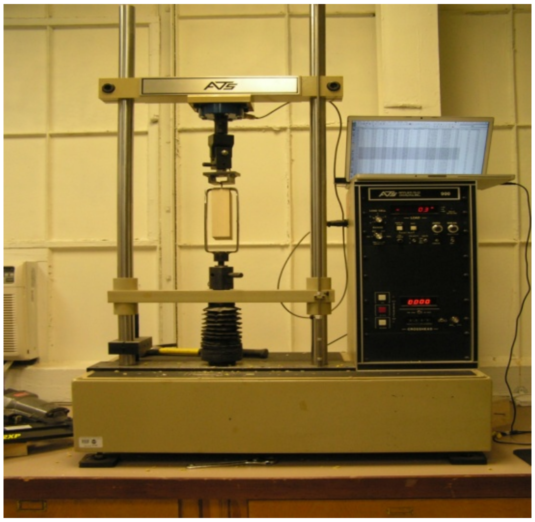

Figure 10. ATS Apparatus withdrawing nail from cross section of block [30]

Nails

Each two by four block was tested with two power-actuated sixteen-penny smooth wire nails (16d)[31]. Nails used for basic withdrawal test were cleaned before use to eliminate any residual coating or surface film from manufacturing operations and exposure. Each nail was used once.

American Society for Testing and Materials D 1761—Withdrawal Procedure

The following withdrawal procedure is outlined in ASTM D 1761 section ten for testing nail withdrawal resistance:

> 10.1 General—Except for special circumstances requiring delayed withdrawal, withdraw fasteners as quickly as practical after driving, and in all cases within 1 hour.
>
> 10.2.1 Where the specimen consists of only the fastening prism and fasteners, withdraw the fasteners by means of a tensile force applied at a

30 Photograph taken by Michael Mizell

31 "d" represents "denarius" which is the Latin word for penny (Wikipedia, n.d.)

uniform rate of withdrawal. Attach the specimen to one platen of the testing machine. Attach the fastener head to a suitably designed grip which is fastened to the other platen through a universal joint. Apply the load by separation of the platens of the testing machine at a uniform rate of withdrawal. Read the maximum load required to withdraw the fastener from the wood or wood product to three significant figures. Disregard test values resulting from any failure of the fastener in the evaluation of the performance of wood and wood-base materials but report them; consider such failures in the evaluation of the performance of different types and sizes of fasteners. In such cases, an additional replication is desirable (p. 282).

Colorado State University Nail Withdrawal Procedure

The following procedure is utilized in the Materials and Testing Laboratory at Colorado State University by Dr. Charles W. Smith for nail withdrawal to expand on the procedure outlined in ASTM D 1761: All nails were seated with three quarters to one inch of the head above the two by four so they could be secured in the ATS Universal Tester. Using a crosshead speed of one tenth of an inch per minute, each nail was pulled until maximum force was displayed on the ATS Universal Tester. Spacer blocks were used for setting nails from the nail gun to allow sufficient room for the gripping device to attach to the nail head. All nails were tested in the same way (Smith, n.d.).

Figure 11. Pneumatic nailing procedure utilizing spacer block to seat nail in cross section of block[32]

[32] Photograph taken by Jenna Brummet

Driving

Nails were driven with a pneumatic nailing gun held at a constant pressure to ensure all nails were driven uniformly. A pneumatic driving system was chosen to reflect the current procedure utilized by modern day framers. This is an important distinction because it has been found that hand driving will result in a twenty-three percent decrease in withdrawal resistance as opposed to machine nailing (Stern, 1963).

Face and Cross Section Procedure for Testing Nail Withdrawal

The following method was utilized for this study to test face and cross section withdrawal resistance:

Each eight foot two by four was cut into six to fourteen, six inch blocks for ease of use with ATS Universal Tester. Two power-actuated sixteen-penny nails were driven into each block—one nail was driven in to each the face and cross section surface. Therefore every two by four provided between twelve and twenty-eight withdrawal tests.

Figure 12. Blocks produced from two by fours[33]

[33] Photograph taken by Michael Mizell

Form of Results

The study was examined as a comparative study attempting to determine differentiating nail withdrawal resistance properties between blue-stained and non-stained lumber. The data was analyzed using a Two-level Analysis of Variance, in conjunction with an Analysis of Covariance to determine if either moisture content or specific gravity affected the results.

CHAPTER 4

Organization of Samples

Ten of each beetle-killed and green trees were harvested from Summit County Colorado for use in this study. After being milled, these trees produced a total of 42 boards. The boards were cut into blocks, generating a total sample size of 440. During the first phase of the board production process, boards showing signs of checking, presence of bark, or signs of decay were discarded. The sample yielded 222 blue-stained and 218 clear blocks. Each block was given a unique one letter, two number identification name. The letter of the name corresponding to the two samples—"B" for Blue-stained blocks, and "C" for Clear wood blocks. The first number after the type classification corresponds to the board, and the final number represents the block within the board. For example, the sixth block produced from the sixth blue-stained board would be given the name " B 6.6."

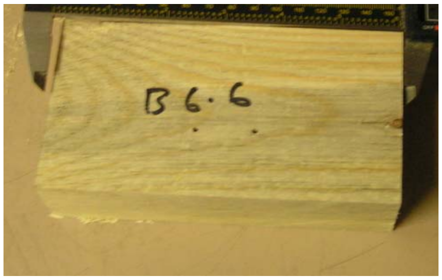

Figure 13. Blue stained block "B 6.6"[34]

[34] Photograph taken by Michael Mizell

The following data analyses were achieved using SAS. For these analyses, the two sample sets are given the name either "B" for blue-stain or "C" for clear wood under the heading of "tree." The withdrawal tests use the identifiers "face" and "cross" for face withdrawal and cross section withdrawal respectively. Finally, moisture content is represented by "moisture" and specific gravity is represented by "SG."

Moisture Content and Specific Gravity

After identifying the sample set, moisture content and specific gravity of all specimens were determined. Moisture content in the specimens ranged from 9.2 to 15.8 percent. The blue-stained sample ranged from 9.2 to 11.6 percent, with a mean of 10.56 percent. The clear wood sample ranged from 9.2 to 15.8 percent, generating a mean of 11.35 percent, which is 0.79 percent higher than the blue-stained mean.

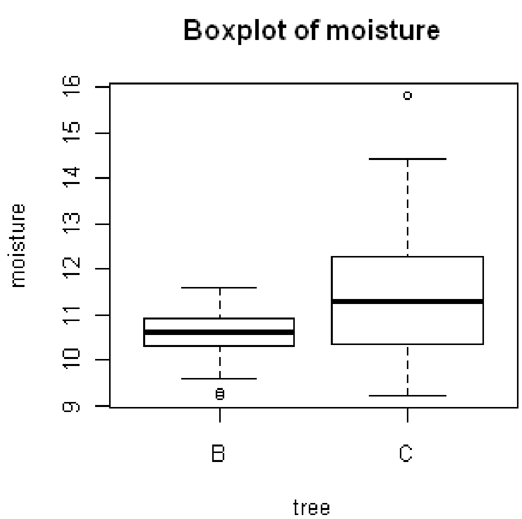

Figure 14. Box Plot[35] showing Moisture Content range in both Blue-stained and Clear wood samples

Table 2
Blue-stained Tree: Moisture Content

Min.	1st Qu.	Median	Mean	3rd Qu.	Max
9.2	10.30	10.60	10.56	10.90	11.60

Table 3
Clear wood: Moisture Content

Min.	1st Qu.	Median	Mean	3rd Qu.	Max
9.20	10.38	11.30	11.35	12.22	15.8

[35] Box Plots show the minimum and maximum values on the two outside whiskers, a box that includes 50% of the samples, and a line in the middle of the box that represents the median. Any outliers are individually marked.

Specific gravity was also determined for each sample. The specific gravity in the test specimens ranged from .35 to .48 in both non-stained and blue-stained blocks. The blue-stained sample ranged from .35 to .476, with a mean of .399, while the clear wood sample ranged from .347 to .4765, with a mean of .393, which is a value 0.0057 lower than the blue-stained samples.

Figure 15. Specific Gravity range in both Blue-stained and Clear wood samples

Table 4
Blue-stained Tree: Specific Gravity

Min.	1stQu	Median	Mean	3rdQu.	Max
0.350	0.390	0.400	0.399	0.410	0.476

Table 5
Clear Wood: Specific Gravity

Min.	1stQu	Median	Mean	3rdQu.	Max
0.347	0.371	0.391	0.393	0.410	0.4765

Face and Cross Sectional Withdrawal Tests

After the moisture content and specific gravity was evaluated for each block, the withdrawal test was performed on both the face and cross section surfaces. The blue-stained face withdrawal test produced a range from 388 to 722 lbs of resistance, generating a mean of 546, with two NA's for two blocks that split while driving the nail. These two samples were dropped from the study. The clear wood face withdrawal test produced ranges from 306 to 705 lbs of resistance, generating a mean of 543. The average blue-stained face withdrawal results produced 3 lbs more resistance than the clear wood.

The blue-stained cross section withdrawal test produced ranges from 340 to 707 lbs of resistance, generating a mean of 467. The clear wood cross section withdrawal test produced ranges from 253 to 672 lbs of resistance, generating a mean of 491. The average clear wood cross section withdrawal results produced 24 lbs more resistance than the blue-stained wood.

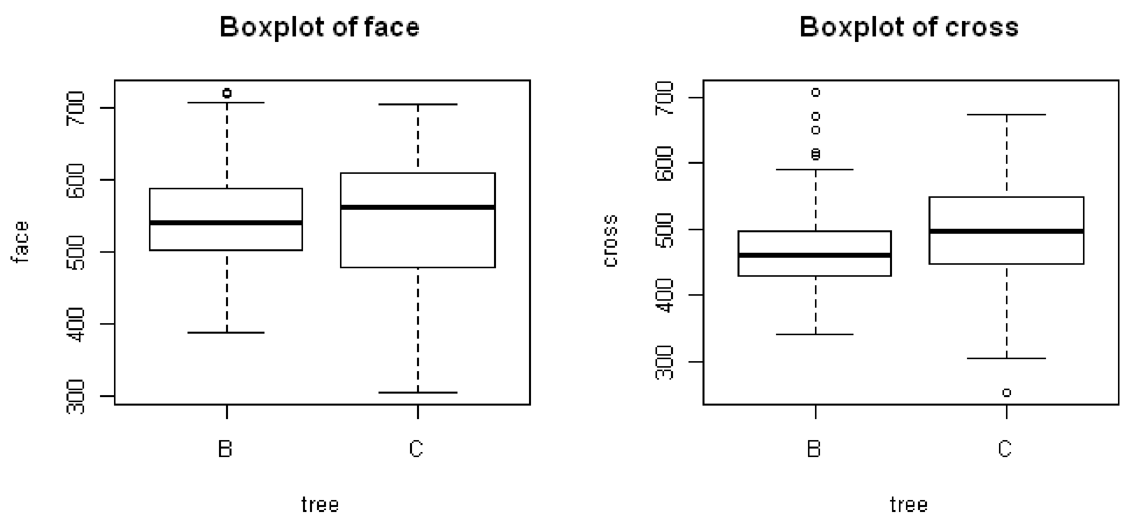

Figure 16. Face and cross section withdrawal box plots for both blue-stained and clear wood

Table 6
Blue-stain Withdrawal vs. Clear Wood Withdrawal

Wood Type/Withdrawal Type	Min.	1st Qu	Median	Mean	3rd Qu.	Max	Split during driving
Blue-stained Tree: Face	388	502	542	546	588	722	2
Blue-stained Tree: Cross Section	340	428	461	467	497	707	0
Clear Wood: Face	306	480	561	543	610	705	0
Clear Wood: Cross Section	253	478	496	491	548	672	0

Analysis of Variance Tests

In order to determine if the four variables of moisture content, specific gravity, face withdrawal and cross sectional withdrawal had significant differences between the two types of wood, Analysis of Variance, or ANOVA tests were run for each. Because there seemed to be a few outliers shown in the Box Plot analysis, this analysis was run on the board level. A mean was taken from each board reducing the sample size from 440 to 42.

The first test analyzes the relationship that moisture takes between the two types of wood. The *p*-value for this test is 0.0014 which rejects the null hypothesis. On the board level, the blue-stained wood has a moisture content 0.766% lower than that of the clear wood samples, and at the 95% confidence level, the blue-stained samples were between 0.314 and 1.216% lower in moisture content than clear wood.

Table 7
Two Level ANOVA – Moisture Content Blue-stain vs. Clear Wood

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
tree	1	40	11.75	0.0014

Least Squares Means

Effect	tree	Estimate	Standard Error	DF	t Value	Pr > |t|	Alpha	Lower	Upper
tree	B	10.557	0.158	40	66.86	<.0001	0.05	10.238	10.8763
tree	C	11.323	0.158	40	71.71	<.0001	0.05	11.004	11.641

Differences of Least Squares Means

Effect	tree	tree	Estimate	Standard Error	DF	t Value	Pr > |t|	Alpha	Lower	Upper
tree	B	C	-0.766	0.223	40	-3.43	0.0014	0.05	-1.217	-0.314

The next test analyzes the relationship that specific gravity takes between the two types of wood. The *p*-value for this test is much larger than the moisture value at 0.253. Such a large number causes acceptance of the null hypothesis. The point estimate for the difference in the two specific gravity means is 0.007. The 95% confidence interval for specific gravity between the two types of wood is between -0.005 and 0.019, which contains zero.

Table 8
Two Level ANOVA – Specific Gravity Blue-stain vs. Clear Wood

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
tree	1	40	1.35	0.252

Least Squares Means

Effect	tree	Estimate	Standard Error	DF	t Value	Pr > |t|	Alpha	Lower	Upper
tree	B	0.399	0.004	40	95.39	<.0001	0.05	0.39	0.407
tree	C	0.392	0.004	40	93.75	<.0001	0.05	0.384	0.4

Differences of Least Squares Means

Effect	tree	tree	Estimate	Standard Error	DF	t Value	Pr > |t|	Alpha	Lower	Upper
tree	B	C	0.007	0.006	40	1.16	0.253	0.05	-0.005	0.019

In the third ANOVA test, examines the difference in face withdrawal resistance between both types of wood. With a *p*-value of 0.985, the null hypothesis cannot be rejected. The point estimate for the difference in the two specific gravity means is -0.374. The 95% confidence interval for specific gravity between the two types of wood is between -39.875 and 39.126, which also contains zero.

Table 9

Two Level ANOVA – Face Withdrawal Blue-stain vs. Clear Wood

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
tree	1	40	0	0.985

Least Squares Means

Effect	tree	Estimate	Standard Error	DF	t Value	Pr > |t|	Alpha	Lower	Upper
tree	B	540.62	13.82	40	39.12	<.0001	0.05	512.69	568.55
tree	C	540.99	13.82	40	39.15	<.0001	0.05	513.06	568.92

Differences of Least Squares Means

Effect	tree	tree	Estimate	Standard Error	DF	t Value	Pr > |t|	Alpha	Lower	Upper
tree	B	C	-0.3742	19.544	40	-0.02	0.985	0.05	-39.875	39.126

Finally in the last ANOVA test, examines the difference in cross sectional withdrawal resistance between both types of wood. With a *p*-value of 0.17, the null hypothesis cannot be rejected. The point estimate for the difference in the two specific gravity means is -22.514. The 95% confidence interval for specific gravity between the two types of wood is between -55.054 and 10.026, which also contains zero.

Table 10
Two Level ANOVA – Cross Section Withdrawal Blue-stain vs. Clear Wood

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
tree	1	40	1.96	0.170

Least Squares Means

Effect	tree	Estimate	Standard Error	DF	t Value	Pr > |t|	Alpha	Lower	Upper
tree	B	468.79	11.385	40	41.18	<.0001	0.05	445.78	491.8
tree	C	491.3	11.385	40	43.15	<.0001	0.05	168.29	514.31

Differences of Least Squares Means

Effect	tree	tree	Estimate	Standard Error	DF	t Value	Pr > |t|	Alpha	Lower	Upper
tree	B	C	-22.514	16.1	40	-1.4	0.17	0.05	-55.054	10.026

Analysis of Covariance Tests

The Analysis of Covariance or ANCOVA, was chosen to determine how the two samples tested while accounting for moisture content or specific gravity, and to develop prediction equations for each variable. The ANCOVA helps to determine how moisture content or specific gravity variables affect withdrawal resistances. The first test was set up to analyze the effect that moisture has on face withdrawal between the two types of wood.

A comparison of face withdrawal between blue-stained wood and clear wood was performed to determine if the results were affected by moisture content. The Type I SS for the two types of wood, or the difference in the means disregarding the covariate is 1.47. The Type III SS for the two types of wood, or the differences between the LS-means controlling for the covariate is 11906.553. The Type I test is not significant with a p-value of 0.982, but the Type III test is significant with a p-value of 0.044, which is below to 0.05.

Table 11
ANCOVA – Moisture Content and Face Withdrawal

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	53458.292	26729.146	9.71	0.0004
Error	39	106974.407	2742.934		
Corrected Total	41	160432.698			

R-Square	Coeff Var	Root MSE	face Mean
0.333	9.684	52.373	540.807

Source	DF	Type I SS	Mean Square	F Value	Pr > F
tree	1	1.47	1.47	0	0.982
Moisture	1	53456.822	53456.822	19.49	<.0001

Source	DF	Type III SS	Means Square	F Value	Pr > F
tree	1	11906.553	11906.553	4.34	0.0438
moisture	1	53456.822	53456.822	19.49	<.0001

Parameter	Estimate	Standard Error	t Value	Pr > |t|
Intercept	-31.085B	130.09	-0.24	0.812
tree B	38.303B	18.385	2.08	0.044
tree C	0.00B	.	.	.
moisture	50.525	11.445	4.41	<.0001

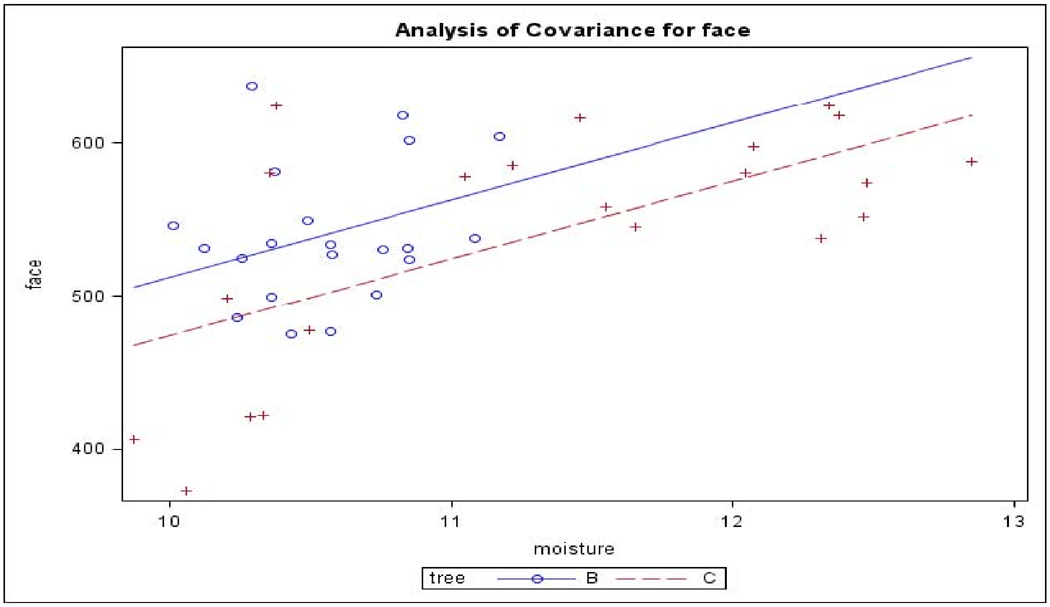

Figure 17. ANCOVA for moisture content and face withdrawal

The predictive formulas from this test to estimate face withdrawal based on moisture is as follows:

Face withdrawal for blue-stained wood = (-31.085 + 38.303) + 50.525 * moisture

Face withdrawal for clear wood = -31.085 + 50.525 * moisture

The next ANCOVA analyzes the relationship cross section withdrawal has with moisture content. The plot does not seem to show much difference between the two types of wood. The Type I SS for the two types of wood is 5322.335. The Type III SS for the two types of wood is 624.628. Neither the Type I nor Type III tests are significant with p-values of 0.102 and 0.569 respectively.

Table 12
ANCOVA – Moisture Content and Cross Section Withdrawal

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	40302.348	20151.174	10.64	0.0002
Error	39	73892.588	1894.682		
Corrected Total	41	114194.936			

R-Square	Coeff Var	Root MSE	cross Mean
0.353	9.067	43.528	480.045

Source	DF	Type I SS	Mean Square	F Value	Pr > F
tree	1	5322.335	5322.335	2.81	0.102
Moisture	1	34980.014	34980.014	18.46	0.0001

Source	DF	Type III SS	Means Square	F Value	Pr > F
tree	1	624.628	624.628	0.33	0.569
moisture	1	34980.014	34980.014	18.46	0.0001

Parameter	Estimate	Standard Error	t Value	Pr > |t|
Intercept	28.534B	108.12	0.26	0.793
tree B	8.773B	15.28	0.57	0.569
tree C	0.00B	.	.	.
moisture	40.87	9.512	4.3	0.0001

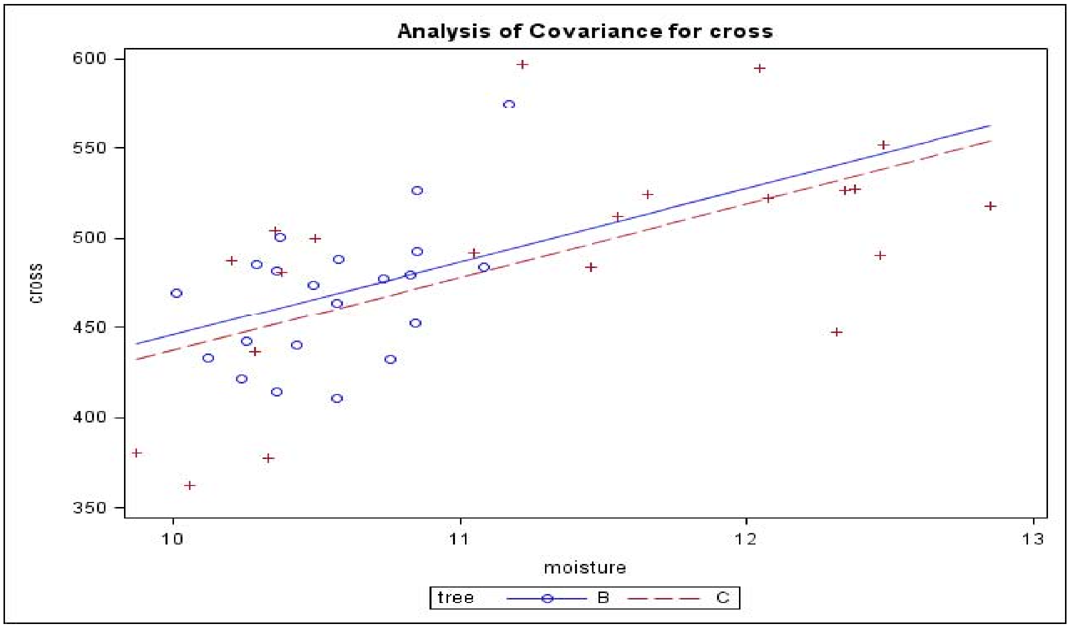

Figure 18. ANCOVA for face cross section withdrawal and moisture

The predictive formulas from this test to estimate cross sectional withdrawal based on moisture is as follows:

Cross section withdrawal for blue-stained wood = (28.534 + 8.773) + 40.871 * moisture

Cross section withdrawal for clear wood = 28.534 + 40.871 * moisture

The third ANCOVA analyzes the relationship face withdrawal has with specific gravity. Again, the plot does not seem to show much difference between the two types of wood. The Type I SS for the two types of wood is 1.470, with the Type III SS for the two types of wood is 1707.603. It is shown again that neither the Type I nor Type III tests are significant with p-values of 0.982 and 0.443 respectively.

Table 13
ANCOVA – Specific Gravity and Face Withdrawal

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	49434.024	24717.012	8.68	0.0008
Error	39	110998.674	2846.12		
Corrected Total	41	160432.698			

R-Square	Coeff Var	Root MSE	face Mean
0.308	9.865	53.349	540.807

Source	DF	Type I SS	Mean Square	F Value	Pr > F
tree	1	1.47	1.47	0	0.982
SG	1	49432.224	49432.224	17.37	0.0002

Source	DF	Type III SS	Means Square	F Value	Pr > F
tree	1	1707.603	1707.603	0.6	0.443
SG	1	49432.554	49432.554	17.37	0.0002

Parameter	Estimate	Standard Error	t Value	Pr > |t|
Intercept	- 178.169B	172.955	-1.03	0.309
tree B	-12.966	16.738	-0.77	0.443
tree C	0.00B	.	.	.
SG	1834.64	440.22	4.17	0.0002

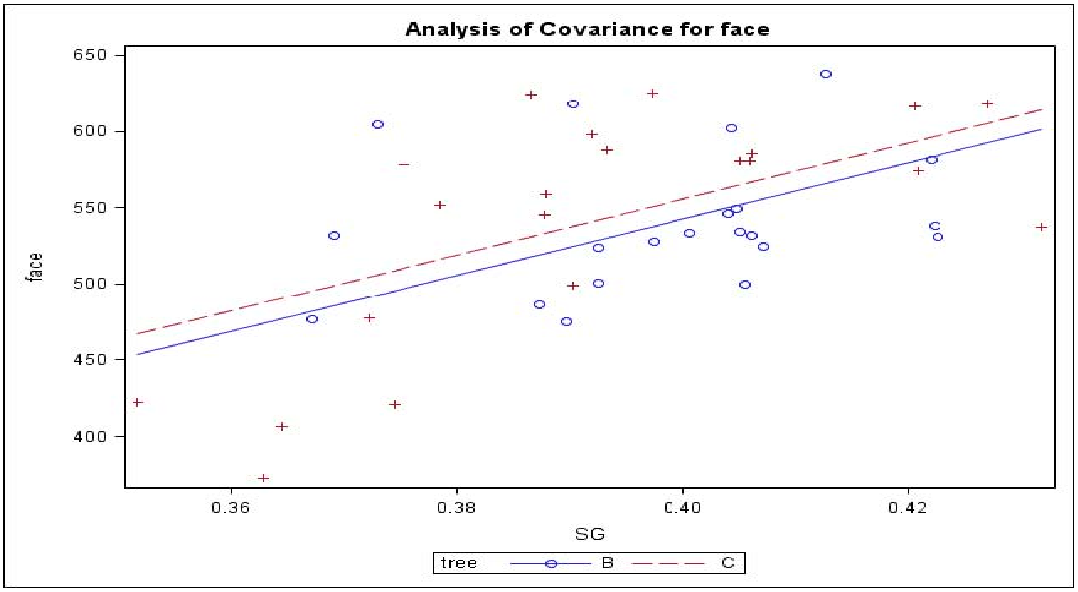

Figure 19. ANCOVA for face withdrawal resistance and specific gravity

The predictive formulas from this test to estimate face withdrawal based on specific gravity is as follows:

Face withdrawal for blue-stained wood = (-178.169 – 12.965552) + 1834.636 * specific gravity

Face withdrawal for clear wood = -178.169 + 1834.636 * specific gravity

The final ANCOVA test analyzes the relationship cross section withdrawal has with specific gravity. This plot seems to show a larger gap between the blue-stained and clear wood lines, with the Type I SS for the two types of wood at 5322.335, and the Type III SS for the two types of wood at 9212.534. However, looking at the p-values, it is determined that these relationships are not significant either, with the Type I value at 0.139 and the Type III value at 0.054.

Table 14
ANCOVA – Specific Gravity and Cross Section Withdrawal

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	23336.802	24717.012	5.01	0.012
Error	39	90858.134	2329.696		
Corrected Total	41	114194.936			

R-Square	Coeff Var	Root MSE	cross Mean
0.204	10.055	48.267	480.045

Source	DF	Type I SS	Mean Square	F Value	Pr > F
tree	1	5322.334	5322.334	2.28	0.139
SG	1	18014.467	18014.467	7.73	0.008

Source	DF	Type III SS	Means Square	F Value	Pr > F
tree	1	9212.534	9212.534	9.95	0.054
SG	1	18014.467	18014.467	7.73	0.008

Parameter	Estimate	Standard Error	t Value	Pr > |t|
Intercept	57.161B	153.479	0.37	0.717
tree B	-30.115 B	15.144	-1.99	0.054
tree C	0.00B	.	.	.
SG	1107.53	398.284	2.78	0.0083

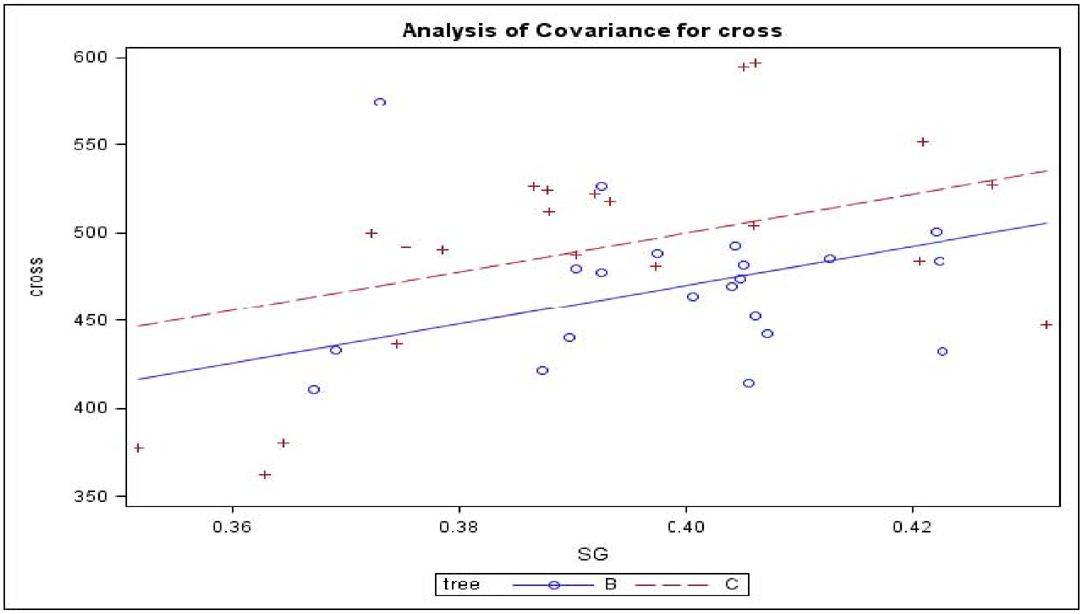

Figure 20. ANCOVA for cross section withdrawal resistance and specific gravity

The predictive formulas from this test to estimate face withdrawal based on specific gravity is as follows:

Cross section withdrawal for blue-stained wood = (57.161 – 30.115) + 1107.526 * specific gravity

Cross section withdrawal for clear wood = 57.161 + 1107.526 * specific gravity

CHAPTER 5

Discussion of Results

The moisture content comparison between the two samples shows that the averages are comparable, with the blue-stained specimens showing a slightly lower moisture content overall. The minimum values are the same, but the maximum values show a difference of 4.2 percent. This suggests that, on average, the two samples were similar; however, there were a few clear wood specimens that may not have reached the equilibrium moisture content during the drying process, thus producing the higher range values.

When comparing specific gravity, face withdrawal, and cross section withdrawal between the two types of wood, it is seen that the ranges and averages are similar, and it can be concluded there is little difference between the two samples in specific gravity, face withdrawal, and cross section withdrawal.

ANOVA

The ANOVA tests determine how significant the differences are in the two types of wood for moisture content, specific gravity, face withdrawal, and cross section withdrawal. In the first test that compares the two moisture content averages, a small *p*-

value of .0014 rejects the null hypothesis, indicating there is a statistical difference between the two types of wood. However, the moisture content reduction of the blue-stained samples was only -0.765%; which is not a practical significance.

In the final three ANOVA analyses, there was no significance in the *p*-values between the two samples in specific gravity, face withdrawal, or cross section withdrawal. In addition all three of the confidence intervals contain zero. This suggests there is no statistical or practical difference between the two types of wood in either specific gravity, face or cross section withdrawal.

ANCOVA

The ANCOVA analyses are intended to determine if withdrawal differences between the blue-stained and clear wood samples are affected by the differences in moisture content or specific gravity. In the Type I test that compares the face withdrawal results of each type of wood, it was found that there was no significance between the means of blue-stained and clear wood. However, when moisture content was taken into account in the Type III SS, the difference between the means of the blue-stained and clear wood became significant. This suggests that given the same level of moisture content, the differences between face withdrawal in blue-stained and clear wood are significant, and that the blue-stained specimens should expect to show approximately 40 lbs more resistance than the clear wood samples. The results show that when moisture content is equalized, the blue-stained wood has a higher mean than the clear wood. This implies that the presence of blue-stained fungus may have a slightly positive effect on face withdrawal.

The final three ANCOVA analyses, which controlled for moisture content and specific gravity on nail withdrawal, were not statistically significant in either the Type I SS or the Type III SS tests. This suggests that blue-stained fungus does not affect withdrawal resistance when controlling for moisture content in cross section withdrawal, or when controlling for specific gravity in either face or cross section withdrawal.

The results of this study show that the difference between blue-stained and clear lodgepole pine face withdrawal resistance was almost 40 lbs of resistance, when controlled for moisture content. The null hypothesis was accepted in all other ANCOVA tests which found neither practical nor statistically significant differences between blue-stain and clear lodgepole pine. It was also shown that the average difference in cross section withdrawal resistance between the blue-stain and clear samples was 23.7 lbs, or a 5 percent increase, in favor of the clear wood samples. Neither moisture content nor specific gravity had an effect on these results.

Conclusion

The mountain pine beetle epidemic has gained momentum to a point that it seems too large to stop with the forest management tactics used in the past. The infestation has taken over many of the logdepole pine stands not only in Summit County, but all over Western North America. While it may be a problem that forest managers cannot control, timber can be salvaged from the situation. In one aspect it is fortunate that these trees have been attacked by the mountain pine beetle, and not some other insect that would destroy the integrity of the sapwood and heartwood. Because these areas are left untouched by the beetle itself, these trees can be harvested for consumption. There are however, set-backs to harvesting and producing blue-stained wood such as unique kiln-drying requirements, and a relatively short shelf-life after beetle attack. These are not the largest obstacles; the most significant obstacles are the negative perceptions faced by consumers. As this study has shown, the differences in nail withdrawal tests performed on blue-stain and clear lumber were not practically significant. In addition, moisture content and specific gravity in the blue-stained samples did not have practical influences on most withdrawal resistances, and that the similar means in withdrawal may be a result of higher moisture content found in the clear wood samples. The study found one significant result when comparing face withdrawal while controlling for moisture content, suggesting that blue-stained wood could possibly yield higher withdrawal resistances over clear wood at the same moisture content. Finally, as it has been shown not only in this research, but in other studies (Lum, 2003; Lum, Byrne & Casilla, 2006; Lam, Jianzhon & Zaturecky, 2006; Levi & Dietrich, 1976; McLain & Ifju, 1982; Sinclair, 1971), blue-stained wood is not, and should not be considered inferior based on mechanical properties alone.

The information gathered from this study adds to the existing literature on the properties of blue-stained lumber and is consistent with the findings of other researchers (Lum, 2003; Lum, Byrne & Casilla, 2006; Lam, Jianzhon & Zaturecky, 2006; Levi & Dietrich, 1976; McLain & Ifju, 1982; Sinclair, 1971). It is imperative for this information to be disseminated to consumers to refute negative assumptions of the effects of blue stain fungus. Failure to take advantage of this merchantable blue-stained lumber, especially in the Front Range will perpetuate the negative trends realized in recent years.

Limitations and Future Research

This research was intended to take a large sample size to determine the differences of withdrawal resistance between blue-stained and clear lumber. At a glance, the sample size was over 400; however, there was not a lot of variability within the source. In all, ten blue-stained, and ten clear lodgepole pine trees from the same stand were used in the study. A larger sample size stemming from a larger quantity of trees may have provided more insight to this study.

The presence of blue-stain in the blue-stained samples varied and were not uniform. Some of the samples had more blue-stain than others, and some only had the stain present on two sides. Given the fact that during the board and block selection process, samples showing the most blue-stain were chosen, a human element was present in this study. While not all samples were purely blue-stained specimens, careful thought was involved in ensuring that when the nail was driven into the blue-stained samples, it was driven into the blue-stained portion of the wood.

Because some of the blue-stained samples were not entirely stained throughout the block, many of the nails driven into the cross section were seated near the edge of the block. When a nail is driven close to an edge of a member, fiber separation could result, thus lowering withdrawal resistances. A future study may benefit from utilizing dimensional lumber generated from trees large enough to produce the entire member from the sapwood, which would eliminate this variable.

As was seen in the results, there was some variability in moisture content between and within the samples. Not only were there differences in the samples, the differences were slightly significant, and had a minor effect on withdrawal results. An overall drying period of nine weeks was used for these samples. A future study may benefit from a longer drying period to ensure all samples reach more similar moisture content levels.

Many of the cited sources admit that few studies exist aimed at identifying the true effect blue-stained fungus has on dimensional lumber, and much of the research that does exist, is old and could be considered outdated. The body of knowledge on blue-stained fungus would benefit from more unique studies, and repetitive studies in the future that could ultimately determine what the structural characteristics of the blue-stained fungus are, and if they have changed over the years.

REFERENCES

American Lumber Standards Committee, Inc. Retrieved September 2007 from http://www.alsc.org/geninfo_summary_mod.htm.

Amman, Gene D, Mark D. McGregor, and Robert E. Dolph Jr. (1990). Mountain Pine Beetle. *Forest Insect and Disease Leaflet*, 2, 1-6.

Annual Book of ASTM Standards. (1994). Philadelphia, Pennsylvania: American Society for Testing and Materials.

Berwyn, Bob. (2006). Pine Beetle Outlook Remains Grim. Summit Daily News Online. Retrieved October 9, 2007 from http://www.summitdaily.com/article/20060707 /NEWS/107070071.

Bowyer, Jim L., Rubin Shmulsky and John G. Haygreen. (2007). *Forest Products and Wood Science*. Ames, Iowa: Blackwell Publishing.

Byrne, Anthony, Cameron Stonestreet, and Brian Peter. (2005). Current Knowledge of characteristics of post-mountain pine beetle wood in solid wood products. *Mountain Pine Beetle Initiative*, 1-18.

Coalition for Advanced Wood Structures. (n.d.) Characterization of Juvenile Wood in Western Softwood Species: Madison WI.

Chow, Suezone. (2007). Moisture and Blue Stain Distribution in Mountain Pine Beetle Infested Lodgepole Pine Trees and Industrial Implications. *Wood Science and Technology*, 41 (1), 3-16.

Colorado Division of Forestry. (2010). Report on the health of Colorado’s forests. *Colorado Department of Natural Resources*, 6.

Colorado State Forest Service. (2006). Report on the Health of Colorado’s Forests. Retrieved September 19, 2007, from http://csfs.colostate.edu/library/ pdfs/fhr/06fhr.pdf.

Colorado Wood Utilization and Marketing Program. *Fact Sheet on Blue-Stain in Lodgepole Pine.* Retrieved September 2, 2007, from http://www.colostate.edu /programs/cowood/New_site/Publications/Articles/Lit_reviews/Blue% 20Stain%20markup.pdf.

Fahey, T.D., T.A. Snellgrove, and M.E. Plank. (1986). Changes in Product Recovery Between Live and Dead Lodgepole Pone: A Compendium. Research Paper. USDA Forest Service, Pacific Northwest Research Station: Portland, OR. 1-25.

Forintek Canada Corp. (2003). Properties of lumber with beetle-transmitted bluestain. *Forintek Canada Corp., Western Division*, Vancouver, B.C. Wood Protection Bulletin, Retrieved September 2, 2007, from http://www.forintek.ca/public/pdf/ woodprotbulltn.pdf.

Goldie, Sean. (n.d.). Working with Blue-Stained Wood. Retrieved October 26, 2007 from http://www.forestnet.com/archives/Feb_04/lumber_research.htm.

Hickman, Lyle. (n.d.). Moisture Content Requirements of the New American Lumber Standards. Portland, Oregon: Western Wood Products Association.

Haynes, R.W., D.M. Adams and J.R. Mills. (1995). The 1993 RPA Timber Assessment Update, General Technical Report RM–GTA–259, Rocky Mountain Forest and Range Experiment Station, United States Department of Agriculture, Fort Collins, Colorado.

Lam, Frank, Jianzhong Gu & Igor Zaturecky. (2006). Performance of Posts Laminated with Mountain Pine Beetle Transmitted Blue-Stain Lodgepole Pine. *Forest Products Journal*, 56 (9), 60-64.

Lemaster, Richard, Harry Troxell, and George Sampson. (1983). Wood Utilization Potential of Beetle-Killed Lodgepole Pine for Solid Wood Products. *Forest Products Journal*, 33 (9), 64-68.

Levi, M.P., and R.L Dietrich. (1976). Utilization of Southern Pine Beetle-Killed Timber. *Forest Products Journal*, 26 (4), 42-47.

Logan, Jesse A, Jacques Regniere and James A. Powell. (2003). Assessing the impacts of global warming on forest pests dynamics. *Frontier in Ecology and the Environment*, 1 (3), 130-137.

Lum, Conroy. (2003). Characterizing the Mechanical Properties of Wood Containing Beetle-transmitted Blue-Stain. *Report to Forest Innovation Investment*, 17.

Lum, Conroy, Tony Byrne and Ronulo Casilla. (2006). Mechanical Properties of Lodgepole Pine Containing Beetle-Transmitted Blue Stain. *Forest Products Journal*, 56 (6), 45-50.

National Lumber Grades Authority. (2003). Standard Grading Rules for Canadian Lumber. *National Lumber Grades Authority*, 274.

Reid, R.W. (1961). Moisture Changes in Lodgepole Pine Before and After Attack by the Mountain Pine Beetle. *Forestry Chronicle*, 368-375.

Robbins, Jim. (2004, July 13). Beetles Take a Devastating Toll on Western Forests. *The New York Times online*. Retrieved September 13, 2007, from http://query.nytimes .com/gst/fullpage.html?res=9D07E3DD1E3BF930A25754C0A9629C8B63 &sec=& spon=&pagewanted=1

Senft J.F. (1971). Withdrawal resistance of plain and galvanized steel nails during changing moisture content conditions. *Forest Products Journal*, 21, 19-24.

Sinclair, Stephen. (1979). Lumber Quality of Beetle-Killed Southern Pine in Virginia. *Forest Products Journal*, 29 (4), 18-22.

Smith, Charles W. (n.d.). Nail Withdrawal Procedures. Unpublished manuscript, Colorado State University.

Soltis, Lawrece A. (n.d.) Fastenings. Madison, Wisconsin. United States Department of Agriculture Forest Service.

Stern, E.G. (1949). Improved Nails – Their Driving Resistance, Withdrawal Resistance and Lateral Load-Carrying Capacity. *Trans American Society of Mechanical Engineers*, 72 (8), 987-988.

Stern, E.G. (1963). Withdrawal resistance of plain-shank and threaded nails of 2 ½ double prime length, driven by hand-hammer vs single-blow Powasert auto. *Virginia Polytechnic Institute, Wood Research Laboratory*, 50, 7-7.

Taylor, SW and AL Carroll. (n.d.). Disturbance, Forest Age, and Mountain Pine Beetle Outbreak Dynamics in BC: A Historical Perspective, 42-51.

Tegethoff, A.C, T.E Hinds and W.E. Eslyn. (1977). Beetle-Killed Lodgepole Pines are Suitable for Powerpoles. *Forest Products Journal*, 27 (9), 21-23.

United States Department of Agriculture Forest Service. Forest Service Introduces Seven-county Bark Beetle Mitigation Plan. Retrieved September 10, 2007, from http://www.fs.fed.us/r2/news/2007/08/aug-31-bb-mitigation.pdf

United States Department of Agriculture Forest Service. (1965) Nail-Withdrawal Resistance of American Woods. Forest Products Laboratory USDA FS: Madison, WI.

Wang, Song-Yung, and Hou-Lin Wang. (1999). Effects of Moisture Content and Specific Gravity on Static Bending Properties and Hardness of Six Wood Species. *The Japanese Wood Research Society*, 45, 127-133.

Western Lumber Grading Rules. (1988). Portland, Oregon: Western Wood Products Association.

Westman, E.F., and J.C. McAdoo. (1969). Nail Withdrawal Resistance of Douglas-fir and Western Hemlock. *Forest Products Journal*, 19 (5), 38.

Wikipedia. (n.d.) Retrieved September 2007, from http://en.wikipedia.org/wiki/Special:Search?search=&fulltext=Search.

Williams D., and E. Mucha. (2003). Characterizing the gluing and finishing properties of wood containing beetle-transmitted bluestain. *Report to Forest Innovation Investment*, 19.

APPENDIX I

Descriptors							Moisture Content and SG		Withdrawal		Type			Notes
Block #	Length (mm)	Width (mm)	Height (mm)	Weight (g)	Calculated ODW	Specific Gravity	Moisture Content	SG	face	cross section	B/C	Stick #	Block #	
B1.1	151.02	47.29	95.60	304.51	274.58	0.40	10.9	0.40	498	707	B	1	1	
B1.2	150.38	47.40	96.32	299.56	269.15	0.39	11.3	0.39	split	504	B	1	2	split
B1.3	151.08	47.45	95.48	296.89	268.92	0.39	10.4	0.39	split	501	B	1	3	split
B1.4	151.29	47.33	95.87	294.26	266.54	0.39	10.4	0.39	530	458	B	1	4	
B1.5	150.02	47.23	95.45	295.44	265.68	0.39	11.2	0.39	547	496	B	1	5	
B1.6	150.10	47.66	95.97	294.30	265.37	0.39	10.9	0.39	520	481	B	1	6	
C1.1	152.49	46.97	96.56	302.19	269.57	0.39	12.1	0.39	531	570	C	1	1	
C1.10	151.88	46.64	96.82	311.29	279.94	0.41	11.2	0.41	463	417	C	1	10	
C1.2	150.60	46.86	96.65	282.61	253.92	0.37	11.3	0.37	531	580	C	1	2	
C1.3	151.52	46.94	96.83	288.83	258.58	0.38	11.7	0.38	549	512	C	1	3	
C1.4	150.68	46.79	97.09	282.52	253.38	0.37	11.5	0.37	546	565	C	1	4	
C1.5	150.89	46.71	96.84	287.35	260.05	0.38	10.5	0.38	560	465	C	1	5	
C1.6	152.02	46.80	96.86	304.03	270.73	0.39	12.3	0.39	667	572	C	1	6	
C1.7	151.65	46.83	96.63	295.50	263.37	0.38	12.2	0.38	530	539	C	1	7	
C1.8	151.22	46.45	96.28	297.31	265.22	0.39	12.1	0.39	567	585	C	1	8	
C1.9	150.60	46.72	96.55	313.05	280.51	0.41	11.6	0.41	513	460	C	1	9	
B2.1	151.45	42.53	96.55	251.77	228.47	0.37	10.2	0.37	547	412	B	2	1	
B2.10	150.87	42.59	97.21	247.27	225.00	0.36	9.9	0.36	574	453	B	2	10	
B2.11	150.55	42.33	96.15	248.26	224.47	0.37	10.6	0.37	577	487	B	2	11	
B2.2	150.93	42.56	96.27	255.32	232.32	0.38	9.9	0.38	408	379	B	2	2	
B2.3	151.26	42.55	96.19	252.01	228.27	0.37	10.4	0.37	479	467	B	2	3	
B2.4	151.31	42.74	96.10	259.13	234.51	0.38	10.5	0.38	511	496	B	2	4	
B2.5	151.00	42.83	95.53	247.38	224.48	0.36	10.2	0.36	544	370	B	2	5	
B2.6	150.00	42.70	96.36	252.78	229.80	0.37	10.0	0.37	578	426	B	2	6	
B2.7	151.00	42.68	96.61	253.56	232.20	0.37	9.2	0.37	578	438	B	2	7	
B2.8	151.82	42.92	96.59	257.75	233.89	0.37	10.2	0.37	550	371	B	2	8	
B2.9	150.51	42.79	96.80	249.00	225.95	0.36	10.2	0.36	502	497	B	2	9	
C2.1	151.50	47.98	97.10	322.30	287.25	0.41	12.2	0.41	613	510	C	2	1	
C2.10	152.01	47.94	95.37	298.22	265.56	0.38	12.3	0.38	638	560	C	2	10	
C2.2	149.80	47.71	96.46	302.53	269.39	0.39	12.3	0.39	613	565	C	2	2	
C2.3	150.03	48.47	96.73	306.19	272.41	0.39	12.4	0.39	670	574	C	2	3	
C2.4	150.18	48.82	95.92	305.78	271.80	0.39	12.5	0.39	546	519	C	2	4	
C2.5	150.71	47.98	95.71	299.08	266.56	0.39	12.2	0.39	675	463	C	2	5	
C2.6	151.17	48.30	95.77	305.57	272.10	0.39	12.3	0.39	675	505	C	2	6	
C2.7	151.15	47.98	95.78	295.69	263.07	0.38	12.4	0.38	625	520	C	2	7	
C2.8	146.64	47.86	95.56	290.65	258.82	0.39	12.3	0.39	585	553	C	2	8	
C2.9	151.21	47.85	95.30	289.65	257.47	0.37	12.5	0.37	605	494	C	2	9	
B3.1	151.11	42.51	97.20	251.99	226.00	0.36	11.5	0.36	593	566	B	3	1	pith
B3.10	151.44	42.78	98.47	265.22	238.29	0.38	11.3	0.38	555	584	B	3	10	
B3.2	151.45	42.69	95.96	258.80	232.73	0.37	11.2	0.37	612	670	B	3	2	
B3.3	151.41	42.49	96.87	264.82	237.93	0.38	11.3	0.38	612	669	B	3	3	
B3.4	151.13	42.76	96.78	255.18	229.48	0.37	11.2	0.37	638	586	B	3	4	
B3.5	150.56	42.60	96.66	258.07	231.60	0.37	11.4	0.37	631	610	B	3	5	
B3.6	150.95	42.64	97.51	253.15	228.68	0.36	10.7	0.36	638	537	B	3	6	
B3.7	150.90	42.62	96.52	273.57	246.02	0.40	11.2	0.40	610	478	B	3	7	
B3.8	150.81	42.41	96.32	246.35	222.14	0.36	10.9	0.36	523	480	B	3	8	
B3.9	151.42	42.60	96.25	255.44	230.13	0.37	11.0	0.37	630	568	B	3	9	
C3.1	150.58	40.84	97.91	263.40	240.99	0.40	9.3	0.40	472	365	C	3	1	
C3.2	152.27	40.53	97.38	235.03	214.64	0.36	9.5	0.36	395	373	C	3	2	
C3.3	152.39	40.47	97.44	238.20	215.57	0.36	10.5	0.36	443	420	C	3	3	
C3.4	152.42	40.53	97.87	238.42	217.34	0.36	9.7	0.36	345	427	C	3	4	
C3.5	151.03	40.67	97.56	233.86	212.21	0.35	10.2	0.35	340	404	C	3	5	
C3.6	151.10	40.76	97.58	239.22	216.49	0.36	10.5	0.36	335	305	C	3	6	
C3.7	151.32	40.69	97.27	239.46	217.30	0.36	10.2	0.36	328	334	C	3	7	
C3.8	151.58	40.59	97.47	238.04	216.01	0.36	10.2	0.36	347	325	C	3	8	
C3.9	150.44	40.67	97.74	232.30	210.42	0.35	10.4	0.35	350	311	C	3	9	
B4.1	150.97	41.63	97.05	261.25	234.94	0.39	11.2	0.39	499	509	B	4	1	heart
B4.2	151.28	41.37	95.72	267.52	242.10	0.40	10.5	0.40	539	497	B	4	2	heart
B4.3	151.83	41.15	96.57	262.55	237.39	0.39	10.6	0.39	517	478	B	4	3	heart
B4.4	150.43	41.60	96.59	263.65	238.38	0.39	10.6	0.39	570	433	B	4	4	heart
B4.5	151.96	41.27	96.33	270.75	245.47	0.41	10.3	0.41	521	486	B	4	5	heart
B4.6	150.69	41.37	95.48	258.04	233.31	0.39	10.6	0.39	511	501	B	4	6	heart

Block #	Length (mm)	Width (mm)	Height (mm)	Weight (g)	Calculated ODW	Specific Gravity	Moisture Content	SG	face	cross section	B/C	Stick #	Block #	
B4.7	151.66	41.11	95.43	269.09	244.18	0.41	10.2	0.41	535	512	B	4	7	heart
C4.1	151.14	46.98	97.45	292.26	261.41	0.38	11.8	0.38	580	479	C	4	1	
C4.2	148.77	47.05	97.12	286.41	256.18	0.38	11.8	0.38	547	534	C	4	2	
C4.3	150.33	46.75	96.89	289.79	258.05	0.38	12.3	0.38	586	520	C	4	3	
C4.4	151.75	46.93	97.10	295.59	266.30	0.39	11.0	0.39	548	511	C	4	4	
C4.5	150.72	46.92	97.95	324.57	287.74	0.42	12.8	0.42	567	517	C	4	5	
C4.6	150.24	47.12	97.74	304.74	270.88	0.39	12.5	0.39	642	549	C	4	6	
C4.7	152.14	46.98	97.72	313.71	278.11	0.40	12.8	0.40	649	506	C	4	7	
C4.8	150.86	46.86	97.33	316.19	283.32	0.41	11.6	0.41	663	559	C	4	8	
B5.1	150.11	42.64	89.57	248.70	223.65	0.39	11.2	0.39	496	512	B	5	1	
B5.2	150.25	42.63	89.60	248.59	225.38	0.39	10.3	0.39	455	502	B	5	2	
B5.3	151.03	42.51	89.28	251.68	226.94	0.40	10.9	0.40	490	449	B	5	3	
B5.4	151.07	42.89	89.77	250.14	224.95	0.39	11.2	0.39	460	410	B	5	4	
B5.5	150.37	42.94	89.31	251.43	227.13	0.39	10.7	0.39	543	470	B	5	5	heart
B5.6	151.05	42.30	89.68	251.51	226.79	0.40	10.9	0.40	503	504	B	5	6	heart
B5.7	151.01	42.51	89.85	248.41	226.03	0.39	9.9	0.39	520	496	B	5	7	heart
C5.1	151.64	41.84	92.09	235.93	214.68	0.37	9.9	0.37	450	354	C	5	1	
C5.10	152.28	41.79	91.63	247.01	224.76	0.39	9.9	0.39	435	451	C	5	10	
C5.2	151.10	41.76	93.53	234.88	213.72	0.36	9.9	0.36	448	434	C	5	2	
C5.3	151.43	41.33	93.00	234.19	211.94	0.36	10.5	0.36	401	492	C	5	3	
C5.4	151.54	41.60	92.34	243.71	220.95	0.38	10.3	0.38	306	370	C	5	4	
C5.5	151.00	41.49	92.66	251.94	228.21	0.39	10.4	0.39	379	424	C	5	5	
C5.6	150.97	41.60	92.43	245.74	222.59	0.38	10.4	0.38	450	360	C	5	6	
C5.7	150.86	41.77	92.43	241.53	218.38	0.37	10.6	0.37	450	455	C	5	7	
C5.8	150.49	41.54	92.60	230.55	208.64	0.36	10.5	0.36	421	506	C	5	8	
C5.9	151.79	41.95	92.11	241.73	218.96	0.37	10.4	0.37	468	479	C	5	9	
B6.1	150.96	42.70	89.31	255.44	233.67	0.41	10.6	0.41	545	479	B	6	1	
B6.10	151.12	42.67	88.89	243.28	219.37	0.38	10.9	0.38	530	416	B	6	10	
B6.11	151.01	42.57	88.95	267.22	242.27	0.42	10.3	0.42	577	526	B	6	11	
B6.12	151.33	42.26	88.63	283.67	257.18	0.45	10.3	0.45	516	615	B	6	12	
B6.13	151.10	42.69	89.47	262.55	237.39	0.41	10.6	0.41	513	484	B	6	13	
B6.14	150.74	42.62	90.00	257.64	233.37	0.40	10.4	0.40	540	472	B	6	14	
B6.15	150.94	42.33	89.45	256.35	231.78	0.41	10.6	0.41	520	538	B	6	15	
B6.2	150.94	42.72	89.25	259.40	234.75	0.41	10.5	0.41	608	519	B	6	2	
B6.3	151.40	42.75	89.08	261.26	237.73	0.41	9.9	0.41	590	532	B	6	3	
B6.4	151.55	42.82	89.78	274.12	248.52	0.43	10.3	0.43	631	590	B	6	4	
B6.5	151.15	42.59	89.56	292.92	267.26	0.46	9.6	0.46	634	480	B	6	5	
B6.6	151.10	42.70	88.76	267.78	241.90	0.42	10.7	0.42	615	535	B	6	6	
B6.7	150.76	42.62	88.90	291.19	264.72	0.46	10.0	0.46	644	429	B	6	7	
B6.8	151.29	42.51	89.33	262.55	237.82	0.41	10.4	0.41	663	493	B	6	8	
B6.9	150.88	42.80	88.94	276.12	250.11	0.44	10.4	0.44	588	420	B	6	9	
C6.1	151.14	48.26	93.73	319.59	284.59	0.42	12.3	0.42	594	580	C	6	1	
C6.10	150.74	48.13	93.80	316.63	284.48	0.42	11.3	0.42	663	477	C	6	10	
C6.2	151.41	48.22	92.93	324.11	288.35	0.42	12.4	0.42	577	509	C	6	2	
C6.3	151.05	48.22	92.34	314.16	280.00	0.42	12.2	0.42	488	554	C	6	3	
C6.4	150.91	48.15	91.85	317.79	283.49	0.42	12.1	0.42	531	534	C	6	4	
C6.5	150.95	48.04	91.56	305.79	274.50	0.41	11.4	0.41	589	477	C	6	5	
C6.6	151.52	47.95	93.44	331.55	294.19	0.43	12.7	0.43	515	641	C	6	6	
C6.7	150.97	48.19	93.53	326.11	285.06	0.42	14.4	0.42	529	572	C	6	7	
C6.8	150.73	48.13	93.77	326.92	287.53	0.42	13.7	0.42	613	617	C	6	8	
C6.9	151.07	48.51	93.60	322.42	287.36	0.42	12.2	0.42	640	554	C	6	9	
B7.1	151.53	40.96	96.02	260.11	234.54	0.39	10.9	0.39	520	396	B	7	1	
B7.2	150.75	41.00	96.30	255.19	231.36	0.39	10.3	0.39	512	388	B	7	2	
B7.3	151.16	40.92	95.89	249.33	226.25	0.38	10.2	0.38	502	438	B	7	3	
B7.4	151.54	41.63	95.76	252.22	229.50	0.38	9.9	0.38	481	502	B	7	4	heart
B7.5	150.77	41.04	95.76	252.76	229.16	0.39	10.3	0.39	393	458	B	7	5	heart
B7.6	151.41	40.84	95.64	255.25	232.47	0.39	9.8	0.39	508	348	B	7	6	
C7.1	150.57	40.85	96.66	243.49	220.55	0.37	10.4	0.37	455	496	C	7	1	
C7.2	151.46	41.28	96.40	273.64	246.74	0.41	10.9	0.41	536	539	C	7	2	
C7.3	151.39	40.95	95.63	240.15	216.52	0.37	9.9	0.37	480	527	C	7	3	
C7.4	151.05	41.16	95.23	244.93	222.06	0.38	10.3	0.38	490	534	C	7	4	
C7.5	151.38	41.07	95.47	239.66	216.10	0.36	10.9	0.36	417	511	C	7	5	
C7.6	151.26	41.23	95.91	236.62	213.17	0.36	11.0	0.36	445	432	C	7	6	

Block #	Length (mm)	Width (mm)	Height (mm)	Weight (g)	Calculated ODW	Specific Gravity	Moisture Content	SG	face	cross section	B/C	Stick #	Block #	
C7.7	151.04	41.44	95.53	247.19	222.70	0.37	10.5	0.37	515	484	C	7	7	
C7.8	151.17	41.40	96.66	241.04	219.13	0.36	10.0	0.36	483	475	C	7	8	
B8.1	151.24	39.86	96.74	261.58	236.72	0.41	10.5	0.41	508	457	B	8	1	heart
B8.2	151.39	39.58	96.52	255.21	230.54	0.40	10.7	0.40	455	470	B	8	2	
B8.3	152.11	39.51	96.60	262.35	236.56	0.41	10.9	0.41	467	435	B	8	3	
B8.4	150.99	39.35	96.42	272.71	247.47	0.43	10.2	0.43	604	418	B	8	4	
B8.5	152.14	39.84	96.78	274.15	249.23	0.42	10.0	0.42	528	397	B	8	5	
B8.6	151.86	39.71	96.07	252.60	229.64	0.40	10.0	0.40	528	392	B	8	6	
B8.7	151.01	39.56	96.03	252.84	229.02	0.40	10.4	0.40	432	376	B	8	7	
B8.8	151.97	39.58	96.33	251.54	228.20	0.39	10.2	0.39	488	384	B	8	8	
B8.9	150.98	39.59	96.02	247.65	224.52	0.39	10.3	0.39	489	400	B	8	9	
C8.1	151.23	43.86	96.85	280.00	246.91	0.38	13.4	0.38	529	498	C	8	1	
C8.2	150.57	44.07	96.91	274.26	243.79	0.38	12.5	0.38	569	447	C	8	2	
C8.3	151.20	43.88	96.95	271.61	241.65	0.38	12.4	0.38	571	481	C	8	3	
C8.4	150.76	43.96	96.64	268.44	239.25	0.37	12.2	0.37	529	468	C	8	4	
C8.5	152.92	43.95	96.90	285.79	254.71	0.39	12.2	0.39	575	550	C	8	5	
C8.6	151.09	43.75	96.66	270.50	241.09	0.38	12.2	0.38	501	481	C	8	6	
C8.7	151.39	44.09	96.64	272.16	241.71	0.37	12.6	0.37	590	519	C	8	7	
C8.8	151.14	44.50	96.55	271.16	241.68	0.37	12.2	0.37	553	500	C	8	8	
B9.1	151.15	44.73	95.26	313.34	282.29	0.44	11.0	0.44	719	450	B	9	1	
B9.10	151.68	44.54	95.84	280.77	252.49	0.39	11.2	0.39	645	649	B	9	10	
B9.11	151.68	44.54	95.84	280.77	252.49	0.39	11.2	0.39	643	545	B	9	11	
B9.12	151.88	44.54	95.72	287.73	260.86	0.40	10.3	0.40	584	491	B	9	12	
B9.13	151.30	44.33	95.24	286.04	257.93	0.40	10.9	0.40	579	517	B	9	13	
B9.14	151.64	44.44	94.01	289.28	260.85	0.41	10.9	0.41	530	533	B	9	14	
B9.15	151.34	44.36	94.37	274.84	247.83	0.39	10.9	0.39	612	381	B	9	15	heart
B9.2	151.05	44.88	94.76	290.35	261.81	0.41	10.9	0.41	626	382	B	9	2	
B9.3	151.88	44.67	96.34	294.39	267.87	0.41	9.9	0.41	607	404	B	9	3	
B9.4	151.80	44.58	94.94	285.94	256.68	0.40	11.4	0.40	644	455	B	9	4	
B9.5	152.54	44.49	97.12	279.20	254.28	0.39	9.8	0.39	604	521	B	9	5	heart
B9.6	151.51	44.94	95.20	299.38	269.95	0.42	10.9	0.42	515	424	B	9	6	
B9.7	151.37	44.43	94.93	299.99	269.78	0.42	11.2	0.42	559	547	B	9	7	
B9.8	151.84	44.44	93.99	276.19	247.93	0.39	11.4	0.39	559	536	B	9	8	
C9.1	152.78	48.00	93.16	330.05	292.08	0.42	13.0	0.42	553	488	C	9	1	
C9.10	152.36	47.52	93.74	334.00	297.68	0.44	12.2	0.44	696	447	C	9	10	
C9.11	154.15	47.55	93.34	347.60	309.25	0.45	12.4	0.45	542	490	C	9	11	
C9.12	152.58	47.43	93.39	334.19	296.27	0.44	12.8	0.44	691	486	C	9	12	
C9.13	152.05	47.61	92.99	336.47	299.35	0.44	12.4	0.44	690	553	C	9	13	
C9.14	154.24	47.47	93.31	326.36	290.61	0.43	12.3	0.43	612	464	C	9	14	
C9.15	154.21	47.33	92.95	318.54	285.69	0.42	11.5	0.42	585	450	C	9	15	
C9.2	154.32	47.58	92.91	322.76	286.66	0.42	12.6	0.42	588	624	C	9	2	
C9.3	154.07	47.52	93.54	317.77	280.47	0.41	13.3	0.41	635	593	C	9	3	
C9.4	153.52	47.48	92.71	314.53	280.08	0.41	12.3	0.41	619	640	C	9	4	
C9.5	153.65	47.55	93.20	316.22	281.33	0.41	12.4	0.41	600	517	C	9	5	
C9.6	151.25	47.32	93.37	301.69	270.33	0.40	11.6	0.40	594	530	C	9	6	
C9.7	152.90	47.60	92.30	311.04	283.02	0.42	9.9	0.42	610	565	C	9	7	
C9.8	153.30	47.45	92.81	340.94	300.12	0.44	13.6	0.44	648	555	C	9	8	
C9.9	153.12	47.56	92.84	333.59	294.43	0.43	13.3	0.43	611	505	C	9	9	
B10.1	151.64	43.23	97.71	289.76	262.46	0.41	10.4	0.41	563	481	B	10	1	
B10.2	151.71	43.12	97.66	293.64	264.78	0.41	10.9	0.41	597	447	B	10	2	
B10.3	151.33	43.37	97.29	286.13	260.35	0.41	9.9	0.41	607	599	B	10	3	
B10.4	151.38	43.43	97.65	279.83	256.02	0.40	9.3	0.40	557	484	B	10	4	
B10.5	151.72	43.46	98.85	289.87	264.00	0.41	9.8	0.41	508	478	B	10	5	
B10.6	150.89	43.03	97.46	282.62	253.93	0.40	11.3	0.40	448	453	B	10	6	
B10.7	151.24	43.05	96.45	277.83	250.52	0.40	10.9	0.40	461	492	B	10	7	
C10.1	151.20	42.68	95.80	246.77	222.52	0.36	10.9	0.36	412	378	C	10	1	
C10.10	150.85	42.62	96.39	240.07	217.65	0.35	10.3	0.35	366	390	C	10	10	
C10.2	151.46	42.42	95.33	238.67	215.84	0.35	10.3	0.35	431	320	C	10	2	
C10.3	151.10	42.46	95.88	245.20	222.10	0.36	10.4	0.36	419	335	C	10	3	
C10.4	150.70	42.38	96.38	236.01	214.55	0.35	10.0	0.35	427	436	C	10	4	
C10.5	151.03	42.58	96.60	237.22	215.16	0.35	10.3	0.35	473	461	C	10	5	
C10.6	151.49	42.37	97.31	242.10	219.10	0.35	10.5	0.35	422	431	C	10	6	
C10.7	151.20	42.55	97.26	240.07	217.65	0.35	10.3	0.35	421	365	C	10	7	

Block #	Length (mm)	Width (mm)	Height (mm)	Weight (g)	Calculated ODW	Specific Gravity	Moisture Content	SG	face	cross section	B/C	Stick #	Block #
C10.8	150.27	42.63	97.24	240.35	218.70	0.35	9.9	0.35	433	312	C	10	8
C10.9	151.04	42.60	96.76	238.14	215.71	0.35	10.4	0.35	416	345	C	10	9
B11.1	151.51	41.09	96.57	272.29	248.44	0.41	9.6	0.41	458	542	B	11	1
B11.2	151.31	40.97	96.71	269.48	244.98	0.41	10.0	0.41	534	449	B	11	2
B11.3	151.85	40.96	96.13	269.82	245.74	0.41	9.8	0.41	542	482	B	11	3
B11.4	150.82	40.86	96.83	269.91	244.48	0.41	10.4	0.41	580	520	B	11	4
B11.5	151.95	40.95	96.61	267.90	245.33	0.41	9.2	0.41	578	447	B	11	5
B11.6	151.24	40.91	96.76	262.50	239.51	0.40	9.6	0.40	536	427	B	11	6
B11.7	150.64	40.97	97.00	264.77	239.39	0.40	10.6	0.40	551	485	B	11	7
B11.8	152.17	40.93	96.74	263.89	239.46	0.40	10.2	0.40	555	426	B	11	8
B11.9	150.51	40.90	96.65	255.74	231.02	0.39	10.7	0.39	541	446	B	11	9
C11.1	149.89	48.06	92.23	314.03	277.90	0.42	13.0	0.42	607	672	C	11	1
C11.10	152.07	47.98	92.05	303.91	270.62	0.40	12.3	0.40	583	655	C	11	10
C11.11	152.05	48.01	92.25	300.57	270.30	0.40	11.2	0.40	647	585	C	11	11
C11.12	150.75	48.04	91.78	293.60	265.46	0.40	10.6	0.40	567	540	C	11	12
C11.2	149.40	47.98	91.39	295.14	262.81	0.40	12.3	0.40	583	598	C	11	2
C11.3	151.11	48.14	91.03	294.51	263.66	0.40	11.7	0.40	570	574	C	11	3
C11.4	151.53	48.66	90.53	291.81	260.31	0.39	12.1	0.39	478	548	C	11	4
C11.5	150.66	48.15	91.77	294.41	264.04	0.40	11.5	0.40	523	624	C	11	5
C11.6	150.78	48.41	92.78	293.00	267.58	0.40	9.5	0.40	483	568	C	11	6
C11.7	150.43	48.18	92.33	331.06	289.39	0.43	14.4	0.43	589	576	C	11	7
C11.8	150.62	48.04	91.97	312.62	275.44	0.41	13.5	0.41	666	611	C	11	8
C11.9	150.73	48.04	91.86	307.91	273.94	0.41	12.4	0.41	674	584	C	11	9
B12.1	150.55	44.89	96.38	295.11	267.07	0.41	10.5	0.41	583	429	B	12	1
B12.10	150.57	44.90	96.05	297.72	268.94	0.41	10.7	0.41	649	472	B	12	10
B12.2	152.26	44.98	96.22	301.79	274.85	0.42	9.8	0.42	586	477	B	12	2
B12.3	150.49	44.96	96.65	300.11	271.35	0.41	10.6	0.41	676	534	B	12	3
B12.4	150.51	44.85	96.39	298.07	269.75	0.41	10.5	0.41	722	561	B	12	4
B12.5	149.95	45.02	96.76	293.18	268.48	0.41	9.2	0.41	645	459	B	12	5
B12.6	151.45	45.19	95.26	302.19	273.23	0.41	10.6	0.41	652	440	B	12	6
B12.7	150.92	45.67	96.01	296.58	268.88	0.41	10.3	0.41	638	515	B	12	7
B12.8	151.22	45.31	96.25	301.45	274.79	0.42	9.7	0.42	574	490	B	12	8
B12.9	150.30	45.08	96.27	295.19	265.94	0.41	11.0	0.41	649	481	B	12	9
C12.1	151.02	47.12	97.75	285.53	257.23	0.37	11.0	0.37	515	439	C	12	1
C12.10	150.76	47.27	95.96	280.76	255.24	0.37	10.0	0.37	519	484	C	12	10
C12.11	152.21	47.05	95.65	291.00	262.40	0.38	10.9	0.38	614	503	C	12	11
C12.2	151.43	47.28	98.25	293.24	263.23	0.37	11.4	0.37	590	496	C	12	2
C12.3	150.90	47.25	98.32	291.00	261.22	0.37	11.4	0.37	613	476	C	12	3
C12.4	151.33	47.26	98.27	300.93	271.11	0.39	11.0	0.39	613	529	C	12	4
C12.5	150.80	47.06	97.74	299.25	271.55	0.39	10.2	0.39	599	540	C	12	5
C12.6	150.80	47.14	97.60	288.41	259.13	0.37	11.3	0.37	554	470	C	12	6
C12.7	151.05	47.38	97.18	283.23	253.79	0.36	11.6	0.36	650	419	C	12	7
C12.8	150.60	47.53	96.75	280.12	251.23	0.36	11.5	0.36	525	463	C	12	8
C12.9	151.60	47.25	96.54	295.05	265.33	0.38	11.2	0.38	563	596	C	12	9
B13.1	154.40	40.51	94.52	260.79	236.44	0.40	10.3	0.40	388	427	B	13	1
B13.10	153.99	40.50	94.50	260.67	235.05	0.40	10.9	0.40	578	454	B	13	10
B13.11	153.53	40.57	94.85	281.34	255.07	0.43	10.3	0.43	578	454	B	13	11
B13.12	154.62	40.66	95.19	258.87	235.98	0.39	9.7	0.39	556	447	B	13	12
B13.13	154.70	40.56	95.73	273.67	247.44	0.41	10.6	0.41	603	445	B	13	13
B13.14	152.70	40.66	95.34	261.35	237.16	0.40	10.2	0.40	536	450	B	13	14
B13.15	155.51	40.35	94.39	257.88	232.53	0.39	10.9	0.39	561	389	B	13	15
B13.2	155.74	40.68	95.46	290.59	262.03	0.43	10.9	0.43	488	477	B	13	2
B13.3	152.65	40.65	95.78	268.45	243.38	0.41	10.3	0.41	529	387	B	13	3
B13.4	154.51	40.61	94.93	270.53	246.38	0.41	9.8	0.41	435	394	B	13	4
B13.5	154.05	40.58	95.30	263.48	239.75	0.40	9.9	0.40	484	416	B	13	5
B13.6	153.35	40.62	95.76	268.31	242.81	0.41	10.5	0.41	518	440	B	13	6
B13.7	155.25	40.32	95.79	266.77	244.07	0.41	9.3	0.41	522	426	B	13	7
B13.8	155.99	40.69	95.68	270.27	244.81	0.40	10.4	0.40	524	538	B	13	8
B13.9	153.98	40.54	95.30	262.21	238.81	0.40	9.8	0.40	558	486	B	13	9
C13.1	151.05	39.58	92.61	221.28	201.16	0.36	10.0	0.36	378	316	C	13	1
C13.10	150.85	39.90	92.98	228.16	207.04	0.37	10.2	0.37	415	388	C	13	10
C13.11	150.94	39.96	92.79	219.91	199.92	0.36	10.0	0.36	379	395	C	13	11
C13.12	151.10	39.57	92.41	219.93	201.22	0.36	9.3	0.36	407	426	C	13	12

Block #	Length (mm)	Width (mm)	Height (mm)	Weight (g)	Calculated ODW	Specific Gravity	Moisture Content	SG	face	cross section	B/C	Stick #	Block #	
C13.13	151.02	39.69	91.96	221.53	202.87	0.37	9.2	0.37	382	374	C	13	13	
C13.2	150.63	39.63	92.69	221.07	201.16	0.36	9.9	0.36	396	338	C	13	2	
C13.3	150.69	39.49	92.09	220.09	200.26	0.37	9.9	0.37	406	347	C	13	3	
C13.4	151.04	40.08	91.73	224.86	204.05	0.37	10.2	0.37	427	374	C	13	4	
C13.5	150.55	39.51	91.59	221.14	201.40	0.37	9.8	0.37	444	396	C	13	5	
C13.6	151.04	39.48	91.35	228.26	208.08	0.38	9.7	0.38	475	423	C	13	6	
C13.7	151.60	40.12	93.59	218.74	199.04	0.35	9.9	0.35	389	422	C	13	7	
C13.8	151.27	39.85	93.28	222.90	202.09	0.36	10.3	0.36	366	361	C	13	8	
C13.9	150.80	40.06	93.07	220.52	200.66	0.36	9.9	0.36	418	411	C	13	9	
B14.1	154.03	41.60	95.81	266.97	240.73	0.39	10.9	0.39	566	420	B	14	1	
B14.10	152.72	41.10	95.64	271.51	244.82	0.41	10.9	0.41	590	437	B	14	10	
B14.11	152.78	40.87	95.28	266.17	240.44	0.40	10.7	0.40	488	489	B	14	11	
B14.12	154.29	40.94	95.56	268.52	241.47	0.40	11.2	0.40	528	460	B	14	12	
B14.13	152.45	40.98	95.85	261.90	236.16	0.39	10.9	0.39	478	462	B	14	13	
B14.14	153.87	41.06	96.14	264.91	238.87	0.39	10.9	0.39	547	439	B	14	14	
B14.2	153.23	41.66	95.55	267.93	242.25	0.40	10.6	0.40	588	409	B	14	2	
B14.3	153.24	41.02	95.80	269.88	243.79	0.40	10.7	0.40	586	494	B	14	3	
B14.4	152.89	41.01	95.50	273.80	248.01	0.41	10.4	0.41	575	436	B	14	4	
B14.5	152.92	41.15	95.44	256.86	232.24	0.39	10.6	0.39	474	458	B	14	5	
B14.6	152.12	41.30	95.75	283.14	257.40	0.43	10.0	0.43	529	487	B	14	6	
B14.7	152.98	41.21	95.86	259.95	236.17	0.39	10.1	0.39	470	543	B	14	7	
B14.8	154.04	41.02	95.57	273.88	248.89	0.41	10.0	0.41	516	486	B	14	8	
B14.9	153.21	41.00	96.49	258.92	235.30	0.39	10.0	0.39	515	476	B	14	9	
C14.1	150.89	46.98	99.25	305.98	275.66	0.39	11.0	0.39	705	520	C	14	1	
C14.2	150.79	47.28	98.58	303.45	275.11	0.39	10.3	0.39	558	491	C	14	2	
C14.3	150.90	47.10	98.72	329.88	299.35	0.43	10.2	0.43	513	253	C	14	3	
C14.4	151.66	47.26	98.88	320.77	291.61	0.41	10.0	0.41	643	452	C	14	4	
C14.5	151.28	47.00	98.75	297.64	269.11	0.38	10.6	0.38	691	527	C	14	5	
C14.6	150.58	47.03	98.00	306.45	279.61	0.40	9.6	0.40	636	555	C	14	6	
C14.7	150.44	47.00	97.37	297.44	268.93	0.39	10.6	0.39	630	594	C	14	7	
C14.8	151.27	47.20	98.52	295.79	267.20	0.38	10.7	0.38	625	459	C	14	8	
B15.1	154.01	44.18	94.48	291.90	263.21	0.41	10.9	0.41	457	471	B	15	1	nm
B15.2	151.87	43.88	98.10	306.50	275.63	0.43	11.2	0.43	550	478	B	15	2	nm
B15.3	152.92	44.06	95.69	306.84	276.43	0.43	11.0	0.43	547	486	B	15	3	
B15.4	153.59	43.79	95.72	306.52	275.40	0.43	11.3	0.43	573	461	B	15	4	
B15.5	151.14	43.53	95.46	309.05	279.18	0.44	10.7	0.44	658	520	B	15	5	
B18.5	154.11	44.13	94.29	284.31	255.22	0.40	11.4	0.40	445	490	B	15	5	
C15.1	151.42	44.67	97.86	294.33	264.69	0.40	11.2	0.40	563	617	C	15	1	
C15.2	152.92	44.17	98.04	297.12	266.00	0.40	11.7	0.40	609	598	C	15	2	
C15.3	151.83	44.52	97.33	293.55	261.88	0.40	12.1	0.40	588	569	C	15	3	
C15.4	150.64	44.30	97.12	301.50	270.16	0.42	11.6	0.42	552	579	C	15	4	
C15.5	151.28	44.52	97.29	295.76	265.49	0.41	11.4	0.41	590	528	C	15	5	
C15.6	151.77	44.31	97.45	299.30	270.61	0.41	10.6	0.41	629	643	C	15	6	
C15.7	151.91	44.06	97.60	293.47	267.03	0.41	9.9	0.41	565	648	C	15	7	
B16.1	154.38	48.97	95.66	318.30	287.02	0.40	10.9	0.40	512	457	B	16	1	
B16.10	155.24	49.32	95.34	319.79	288.10	0.39	11.0	0.39	615	430	B	16	10	
B16.11	153.77	49.11	96.28	310.46	279.19	0.38	11.2	0.38	630	456	B	16	11	
B16.12	153.32	49.33	95.87	306.35	277.49	0.38	10.4	0.38	616	533	B	16	12	
B16.13	153.16	49.03	96.31	331.68	298.81	0.41	11.0	0.41	708	484	B	16	13	
B16.14	153.87	49.22	96.11	307.19	276.75	0.38	11.0	0.38	607	441	B	16	14	
B16.15	152.13	49.23	96.52	310.39	282.17	0.39	10.0	0.39	566	487	B	16	15	
B16.2	153.11	48.57	96.48	309.76	279.05	0.39	11.0	0.39	621	458	B	16	2	
B16.3	153.35	48.91	94.96	301.72	272.06	0.38	10.9	0.38	616	508	B	15	3	
B16.4	154.24	48.95	94.69	315.39	283.62	0.40	11.2	0.40	675	513	B	16	4	
B16.5	153.40	49.03	95.11	319.14	285.97	0.40	11.6	0.40	550	470	B	16	5	
B16.6	154.94	49.04	95.32	309.09	277.96	0.38	11.2	0.38	651	473	B	16	6	
B16.7	155.65	49.39	95.08	305.61	276.32	0.38	10.6	0.38	597	455	B	16	7	
B16.8	152.68	49.25	96.40	306.21	277.38	0.38	10.4	0.38	653	516	B	16	8	
B16.9	152.91	49.09	95.22	313.77	285.25	0.40	10.0	0.40	655	503	B	16	9	
C16.1	153.07	42.66	96.94	309.48	278.81	0.44	11.0	0.44	643	523	C	16	1	
C16.10	149.87	42.11	98.03	244.39	222.17	0.36	10.0	0.36	343	450	C	16	10	
C16.2	152.40	40.26	97.52	260.19	235.47	0.39	10.5	0.39	475	462	C	16	2	
C16.3	151.63	39.77	97.47	252.73	231.23	0.39	9.3	0.39	456	448	C	16	3	

Block #	Length (mm)	Width (mm)	Height (mm)	Weight (g)	Calculated ODW	Specific Gravity	Moisture Content	SG	face	cross section	B/C	Stick #	Block #
C16.4	152.09	39.97	97.82	269.97	245.87	0.41	9.8	0.41	531	499	C	16	4
C16.5	153.84	42.66	97.36	275.90	249.91	0.39	10.4	0.39	531	539	C	16	5
C16.6	152.76	42.88	95.66	253.45	229.99	0.37	10.2	0.37	530	531	C	16	6
C16.7	152.81	42.70	95.80	271.44	246.70	0.39	10.0	0.39	533	439	C	16	7
C16.8	152.38	42.44	96.22	260.48	235.73	0.38	10.5	0.38	466	520	C	16	8
C16.9	151.73	42.32	97.00	253.20	229.56	0.37	10.3	0.37	480	465	C	16	9
B17.1	154.95	41.87	95.34	260.24	234.66	0.38	10.9	0.38	458	427	B	17	1
B17.2	154.12	42.19	95.21	265.98	240.49	0.39	10.6	0.39	539	430	B	17	2
B17.3	153.92	41.75	95.06	273.27	247.30	0.40	10.5	0.40	474	435	B	17	3
B17.4	153.28	42.11	95.18	248.85	225.82	0.37	10.2	0.37	462	415	B	17	4
B17.5	154.41	41.82	95.49	266.14	241.07	0.39	10.4	0.39	462	443	B	17	5
B17.6	153.98	41.96	95.02	270.95	246.32	0.40	10.0	0.40	450	507	B	17	6
B17.7	153.96	41.92	95.00	267.34	242.16	0.39	10.4	0.39	478	426	B	17	7
C17.1	150.87	40.00	97.78	271.39	247.17	0.42	9.8	0.42	545	545	C	17	1
C17.10	151.44	44.41	97.72	295.27	265.05	0.40	11.4	0.40	560	454	C	17	10
C17.11	152.88	44.14	97.69	301.89	271.24	0.41	11.3	0.41	606	464	C	17	11
C17.12	154.12	44.56	96.72	300.45	269.95	0.41	11.3	0.41	552	548	C	17	12
C17.13	153.14	44.35	96.34	299.65	270.20	0.41	10.9	0.41	606	544	C	17	13
C17.14	151.36	44.06	96.76	297.95	267.70	0.41	11.3	0.41	606	466	C	17	14
C17.2	152.14	40.00	96.81	258.13	234.66	0.40	10.0	0.40	603	470	C	17	2
C17.3	151.25	40.02	97.39	255.09	233.39	0.40	9.3	0.40	560	588	C	17	3
C17.4	152.12	39.93	98.34	257.50	233.03	0.39	10.5	0.39	536	491	C	17	4
C17.5	151.97	39.94	95.68	256.47	233.15	0.40	10.0	0.40	525	539	C	17	5
C17.6	152.79	39.66	96.73	259.39	236.89	0.40	9.5	0.40	554	523	C	17	6
C17.7	151.93	39.72	97.16	266.18	243.53	0.42	9.3	0.42	594	550	C	17	7
C17.8	153.10	39.76	97.31	263.09	239.61	0.40	9.8	0.40	615	458	C	17	8
C17.9	151.46	44.37	98.00	298.30	269.95	0.41	10.5	0.41	580	411	C	17	9
B18.1	155.80	44.36	93.30	273.69	248.36	0.39	10.2	0.39	487	488	B	18	1
B18.10	154.99	43.91	93.43	294.43	264.54	0.42	11.3	0.42	534	408	B	18	10
B18.11	155.72	44.08	92.46	302.20	272.99	0.43	10.7	0.43	603	490	B	18	11
B18.12	154.54	44.48	95.76	346.20	313.30	0.48	10.5	0.48	603	545	B	18	12
B18.13	154.70	44.10	96.86	289.36	260.22	0.39	11.2	0.39	522	433	B	18	13
B18.2	155.70	43.88	93.73	297.28	268.05	0.42	10.9	0.42	484	410	B	18	2
B18.3	154.76	44.35	93.64	273.60	246.49	0.38	11.0	0.38	494	406	B	18	3
B18.4	155.13	44.06	93.39	278.07	250.51	0.39	11.0	0.39	456	396	B	18	4
B18.6	155.80	44.01	95.47	278.00	250.45	0.38	11.0	0.38	537	424	B	18	6
B18.7	155.80	44.28	96.35	294.59	266.12	0.40	10.7	0.40	584	504	B	18	7
B18.8	155.10	44.43	93.20	292.91	264.60	0.41	10.7	0.41	525	450	B	18	8
B18.9	154.95	44.35	95.44	281.95	254.24	0.39	10.9	0.39	547	468	B	18	9
C18.1	151.54	47.28	96.03	313.59	279.49	0.41	12.2	0.41	675	442	C	18	1
C18.10	150.58	47.27	96.10	318.26	285.95	0.42	11.3	0.42	607	465	C	18	10
C18.11	151.25	47.34	96.68	336.10	301.98	0.44	11.3	0.44	671	482	C	18	11
C18.12	151.33	47.01	95.32	301.00	272.40	0.40	10.5	0.40	623	435	C	18	12
C18.13	150.62	46.90	94.83	310.64	280.11	0.42	10.9	0.42	597	493	C	18	13
C18.2	150.89	47.35	96.07	317.82	283.51	0.41	12.1	0.41	660	566	C	18	2
C18.3	151.28	47.43	96.43	321.40	288.25	0.42	11.5	0.42	630	600	C	18	3
C18.4	150.49	47.32	97.02	324.58	292.41	0.42	11.0	0.42	655	426	C	18	4
C18.5	150.93	46.93	96.59	320.99	291.28	0.43	10.2	0.43	608	505	C	18	5
C18.6	151.36	47.45	97.30	340.62	305.76	0.44	11.4	0.44	494	478	C	18	6
C18.7	150.94	47.20	97.08	330.44	293.72	0.42	12.5	0.42	574	445	C	18	7
C18.8	150.28	47.28	96.35	330.55	294.61	0.43	12.2	0.43	569	465	C	18	8
C18.9	150.84	47.30	96.42	320.60	286.76	0.42	11.8	0.42	651	486	C	18	9
B19.1	155.55	43.92	92.96	248.09	224.52	0.35	10.5	0.35	483	380	B	19	1
B19.10	154.53	43.74	92.49	262.20	237.72	0.38	10.3	0.38	433	427	B	19	10
B19.11	154.67	43.74	91.97	246.55	223.32	0.36	10.4	0.36	430	433	B	19	11
B19.12	153.81	44.13	92.60	246.77	222.52	0.35	10.9	0.35	505	438	B	19	12
B19.13	153.71	44.00	92.77	250.32	225.72	0.36	10.9	0.36	543	419	B	19	13
B19.14	153.95	43.50	92.35	250.25	226.27	0.37	10.6	0.37	553	435	B	19	14
B19.2	154.88	44.19	91.80	260.40	234.81	0.37	10.9	0.37	514	340	B	19	2
B19.3	155.25	43.34	91.95	251.66	228.16	0.37	10.3	0.37	463	358	B	19	3
B19.4	154.55	43.51	91.81	245.36	221.84	0.36	10.6	0.36	448	455	B	19	4
B19.5	154.63	43.70	91.87	248.84	225.40	0.36	10.4	0.36	476	423	B	19	5
B19.6	154.36	43.79	92.39	271.71	245.67	0.39	10.6	0.39	465	435	B	19	6

Block #	Length (mm)	Width (mm)	Height (mm)	Weight (g)	Calculated ODW	Specific Gravity	Moisture Content	SG	face	cross section	B/C	Stick #	Block #
B19.7	155.70	43.96	92.61	253.57	229.68	0.36	10.4	0.36	462	384	B	19	7
B19.8	154.05	43.85	92.62	253.31	229.45	0.37	10.4	0.37	416	414	B	19	8
B19.9	154.71	43.70	92.64	263.10	237.67	0.38	10.7	0.38	459	424	B	19	9
C19.1	154.64	48.68	95.49	327.19	288.53	0.40	13.4	0.40	651	510	C	19	1
C19.10	155.13	48.40	96.68	331.33	289.62	0.40	14.4	0.40	375	548	C	19	10
C19.11	154.81	48.46	96.86	323.05	283.13	0.39	14.1	0.39	570	445	C	19	11
C19.12	153.87	48.25	96.09	315.30	281.02	0.39	12.2	0.39	610	477	C	19	12
C19.13	150.55	48.07	96.14	328.02	289.77	0.42	13.2	0.42	622	638	C	19	13
C19.14	154.34	48.17	96.10	312.50	278.52	0.39	12.2	0.39	554	457	C	19	14
C19.2	151.55	48.74	96.79	313.05	276.30	0.39	13.3	0.39	640	573	C	19	2
C19.3	154.29	48.24	97.10	310.97	276.17	0.38	12.6	0.38	628	494	C	19	3
C19.4	153.42	48.35	97.31	312.29	278.33	0.39	12.2	0.39	619	521	C	19	4
C19.5	153.77	48.10	96.99	310.17	278.93	0.39	11.2	0.39	549	554	C	19	5
C19.6	152.72	48.17	97.09	302.73	272.24	0.38	11.2	0.38	611	538	C	19	6
C19.7	153.61	47.99	97.11	312.43	281.72	0.39	10.9	0.39	589	453	C	19	7
C19.8	154.73	48.64	96.38	327.69	289.48	0.40	13.2	0.40	580	446	C	19	8
C19.9	153.98	48.18	96.43	334.14	288.55	0.40	15.8	0.40	634	601	C	19	9
B20.1	153.39	40.60	95.89	276.31	250.51	0.42	10.3	0.42	461	399	B	20	1
B20.10	153.98	40.88	96.25	275.53	248.45	0.41	10.9	0.41	549	408	B	20	10
B20.11	153.19	40.89	96.27	284.11	255.95	0.42	11.0	0.42	585	390	B	20	11
B20.12	153.35	40.72	95.82	279.12	251.69	0.42	10.9	0.42	530	424	B	20	12
B20.13	153.37	40.60	96.29	278.94	251.30	0.42	11.0	0.42	411	448	B	20	13
B20.14	155.20	40.95	96.09	288.82	261.14	0.43	10.6	0.43	500	441	B	20	14
B20.2	154.11	40.91	96.37	297.73	268.23	0.44	11.0	0.44	590	439	B	20	2
B20.3	154.78	40.78	96.64	287.72	260.14	0.43	10.6	0.43	565	421	B	20	3
B20.4	154.42	40.71	95.72	275.31	248.25	0.41	10.9	0.41	505	458	B	20	4
B20.5	155.80	40.48	95.88	281.84	254.14	0.42	10.9	0.42	532	476	B	20	5
B20.6	154.32	41.00	95.57	284.07	256.84	0.42	10.6	0.42	581	500	B	20	6
B20.7	152.99	40.48	95.93	282.00	256.36	0.43	10.0	0.43	540	434	B	20	7
B20.8	153.42	40.48	95.78	275.29	248.23	0.42	10.9	0.42	533	414	B	20	8
B20.9	152.55	40.73	96.44	283.78	255.89	0.43	10.9	0.43	527	394	B	20	9
C20.1	150.81	45.68	97.42	295.20	264.75	0.39	11.5	0.39	538	483	C	20	1
C20.2	151.40	45.44	97.39	279.27	250.02	0.37	11.7	0.37	470	537	C	20	2
C20.3	150.90	45.26	97.16	292.38	260.82	0.39	12.1	0.39	496	518	C	20	3
C20.4	151.09	45.19	96.97	273.89	245.42	0.37	11.6	0.37	563	573	C	20	4
C20.5	151.33	45.13	96.55	283.76	255.87	0.39	10.9	0.39	557	513	C	20	5
C20.6	151.56	45.35	97.42	279.24	249.99	0.37	11.7	0.37	589	461	C	20	6
C20.7	150.92	45.33	97.56	289.85	258.56	0.39	12.1	0.39	554	496	C	20	7
C20.8	150.80	45.52	97.63	298.72	268.15	0.40	11.4	0.40	657	491	C	20	8
C20.9	150.71	45.29	97.72	303.41	273.59	0.41	10.9	0.41	605	537	C	20	9
B21.1	154.30	40.91	94.98	266.26	240.09	0.40	10.9	0.40	500	434	B	21	1
B21.10	153.08	40.98	95.78	260.91	236.33	0.39	10.4	0.39	499	487	B	21	10
B21.11	153.83	40.88	95.53	272.22	245.46	0.41	10.9	0.41	570	520	B	21	11
B21.12	153.75	40.83	95.07	268.48	242.97	0.41	10.5	0.41	561	522	B	21	12
B21.2	153.72	40.81	95.62	269.43	244.27	0.41	10.3	0.41	607	461	B	21	2
B21.3	153.89	40.85	95.60	305.54	277.26	0.46	10.2	0.46	566	452	B	21	3
B21.4	154.61	41.12	95.81	265.50	240.71	0.40	10.3	0.40	592	444	B	21	4
B21.5	154.24	40.95	96.13	264.68	239.31	0.39	10.6	0.39	537	480	B	21	5
B21.6	153.10	40.99	96.59	256.45	232.71	0.38	10.2	0.38	513	435	B	21	6
B21.7	153.55	40.84	95.47	267.14	242.19	0.40	10.3	0.40	575	499	B	21	7
B21.8	153.87	40.99	95.17	278.81	250.51	0.42	10.5	0.42	557	428	B	21	8
B21.9	153.69	41.33	96.07	259.47	234.39	0.38	10.7	0.38	500	513	B	21	9
C21.1	150.87	46.31	93.95	307.73	274.27	0.42	12.2	0.42	571	388	C	21	1
C21.10	150.66	46.31	94.36	312.52	277.55	0.42	12.6	0.42	622	467	C	21	10
C21.11	150.51	46.31	93.75	304.80	271.42	0.42	12.3	0.42	599	473	C	21	11
C21.2	151.03	46.48	94.54	307.09	273.70	0.41	12.2	0.41	501	454	C	21	2
C21.3	150.66	46.30	94.33	315.31	280.77	0.43	12.3	0.43	480	497	C	21	3
C21.4	151.08	46.42	94.70	316.33	281.93	0.42	12.2	0.42	513	540	C	21	4
C21.5	151.64	46.48	95.19	321.73	290.63	0.43	10.7	0.43	434	385	C	21	5
C21.6	151.00	46.41	94.71	312.65	278.58	0.42	12.3	0.42	486	310	C	21	6
C21.7	150.93	46.29	94.49	330.87	293.85	0.45	12.6	0.45	580	305	C	21	7
C21.8	151.49	46.41	94.14	341.26	303.07	0.46	12.6	0.46	508	587	C	21	8
C21.9	150.87	46.43	94.16	356.41	314.29	0.48	13.4	0.48	621	511	C	21	9