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CREATING A STRONGER AND MORE WATER-RESISTANT MATERIAL USING
SPRUCE WOOD

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ABSTRACT

Recently, a method that makes wood stronger than steel was reported (Song, et al, 2018). Several types of wood were tested, including both hard and soft woods. In this thesis, the reproducibility of the data reported was tested using spruce wood, a common tree type found in Pennsylvania. The lignin extraction was analyzed and found that extracting 0.42 g of lignin per 10 g wood yields best results. Closely following the published procedure resulted in a 34% increase in density (0.672 g/cm^3), which is significantly less than reported (1.30 g/cm^3). The modified temperature (130°C) and pressure (14.8 MPa) in our experiments resulted in a density of 1.16 g/cm^3. In addition, a procedure intended to improve the water resistance was designed and tested. More specifically, the treated wood was impregnated with 2-hydroxyethyl methacrylate (HEMA) monomer and subsequently irradiated with gamma rays. The modified and compacted wood obtained using the published procedure absorbed 58.5% of its weight in water while the plasticized sample obtained using our procedure absorbed 33.5% of its weight in water. The difference observed through these tests makes pursuing this research worthwhile.

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Chapter 1

Introduction

Wood has been used as a renewable and cheap resource in construction for millennia. Over time, more advanced materials, such as steel and concrete, have become more dominant within the construction industry due to their increased strength. The process of creating steel was simplified in the 1850s, and the Chicago Fire in 1871 sparked the movement towards non-timber-based materials for construction (Long, 2011; Spross, 2019). However, concrete and steel are not renewable resources, are more expensive to produce and buy, and contribute more to greenhouse gas emissions (Bolduc, 2017). With the notion that there are modern technologies available to fireproof wood, and steel is compromised under high heat, what would be the outcome if wood can be engineered to enhance its mechanical performance (Luo, 2016)?

There have been efforts for improving the strength of wood over the past few decades. Some experiments attempted to strengthen wood through densification efforts after steam treatment, cold rolling, or ammonia treatment (Song, et al, 2018). Other researchers attempted to generate a stronger material through cellulose nanofiber extraction (Zastrow, 2018). Cellulose is the primary component of the cell wall consisting of glucose repeat units and giving wood its characteristic grain. Though these research attempts managed to increase the strength of the wood by a factor of 4 at most, a new densification method recently surfaced in February 2018. A research team found that removing 45% of the lignin content through a seven-hour boiling caustic solution prior to compaction increases the strength of the wood by a factor of 11.5 times, making it stronger than steel. The team also reported a 3-fold increase in density (Song, et al, 2018).

Delignating the wood is imperative to the densification process because voids between cellulose chains are formed. Natural wood can be thought to look like an amorphous polymer, consisting of

multiple, straight-chained components mixed with blocky organic molecules throughout. When the lignin

is degraded and extracted from the wood, voids form between the still in-tact cellulose chains. Upon

densification of the block, the distance between the cellulose fibers is reduced. Cellulose is a polymer

consisting of a glucose repeat unit. Glucose contains many hydroxyl groups that can contribute to

hydrogen bonding – the strongest of the intermolecular attractions. The decreased distance between the

cellulose chains increases the amount of hydrogen bonding between these polymers, creating a stronger

material. In the Nature article, the thickness of the wood was reduced to 20% its original size (Song, et al,

2018). The chemical treatment of the block followed by compaction attributed to the significant thickness

reduction because cellulose is a linear polymer that forms a crystalline structure. In order to break

something in half, such as a wood block, the bonds holding the material together must be broken. The

molecular structure of cellulose (A), hemicellulose (B), and lignin (C) are pictured in Figure 1.1.
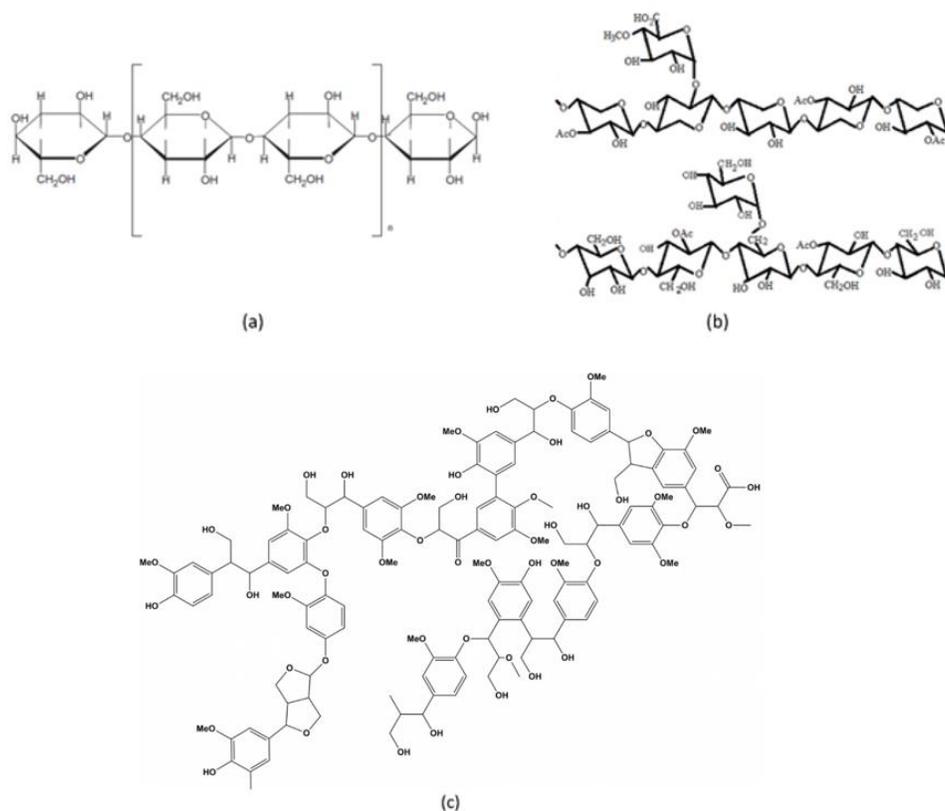
Figure 1.1: Molecular structure of cellulose (a), hemicellulose (b), and lignin (c) (Siregar, 2016).

Wood is susceptible to fungal decay when the moisture content within the wood reaches 16% weight water (Loffer). Processing and densifying the wood may not be enough to combat the moisture absorption necessary for fungal decay, given certain conditions. According to the Nature article, compressed natural wood expands more than compressed delignated wood at 95% relative humidity for 128 hours. The compressed delignated wood with a surface coating of paint experienced little to no expansion under these conditions (Song, et al, 2018). Wood-plastic composites can also combat moisture absorption due to the introduction of a complex polymer matrix within the wood (Ibach and Segerholm, 2013). Previous experiments determined the best polymer loading (PL) occurs with high concentrations of monomer mixed with methanol, achieving a PL of 102% with a mixture containing 70% acrylamide and 30% methanol (Ali and Khan, 1992). A mixture using water as the swelling agent reduces the PL to 68% due to the different interactions between the water, monomer, and cellulose fibers (Ali and Khan, 1992). A new technique using water to swell the wood initially, followed by impregnation of the wood with a monomer may improve the polymer loading. Water will be initially used as the swelling agent by absorbing into the wood by breaking the hydrogen bonds between the cellulose chains. Addition of methanol to a water system to create a binary system leads to the entropy being reduced as water and methanol spontaneously mix (Zhong, Warren, and Patel, 2007). This mixing of the two components leads to the infusion of methanol in the wood block, meeting some conditions found in previous papers (Ali and Khan, 1992). The block can then be impregnated by a monomer, such as HEMA, and irradiated using a Co60 gamma source that will be capable of penetrating the wood.

The goal of this thesis is to strengthen a softwood, such as spruce wood, through chemical processing and densification. The ability to strengthen low-quality timbers would open a plethora of opportunities, especially in the construction of large, wooden structures such as the 800-foot River Beech Skyscraper (Spross, 2019). An image of the conceptual design is pictured in Figure 1.2.

Figure 1.2: Conceptual design of the 800-foot River Beech Tower designed by Perkins+Will (Spross, 2019).

Chapter 2

Materials

In this experiment, a spruce plank was cut into multiple blocks (dimensions of 60 mm by 60 mm by 18 mm) to be chemically treated and densified. One of the densified samples was cut to a smaller size for testing the irradiation and PL of HEMA monomer.

To prepare the wood for densification, the following chemicals were used: sodium hydroxide (>98%, Sigma Aldrich), sodium sulfite (>98%, Alfa Aesar), and deionized water. The following chemicals were used for preparing the solution for HEMA (>97%, Aldrich) impregnation: methanol (99.8%, VWR Chemicals), ethanol (100%, KOPTEC), and 1-propanol (>99.5%, Sigma Aldrich). Pure lignin (Aldrich) was used as a reference sample for UV-spectroscopy. All water baths were prepared using deionized water.

2.1 Densification of Wood Blocks

Eight wood block samples, cut to the above dimensions, were prepared using a 2.5 M NaOH and 0.4 M Na_2SO_3 cooking solution. The blocks were submerged in the boiling solution for seven hours. The cooking solution was used to degrade the lignin and hemicellulose for removal. Degradation of these organic compounds creates voids within the wood so increased compaction can be achieved (Song, et al, 2018).

The blocks were then submerged in multiple deionized water baths to remove additional chemicals and organic components. These baths were set to a temperature of 95°C and the block was set in the bath for an average of seven hours per bath. The samples would be dried when the color of the new

bath no longer changed to a darker brown, as seen in Figure 2.1. The blocks were originally set out to dry

in a vacuum chamber but were later set to dry in the room due to the formation of cracks from drying the

blocks too rapidly.
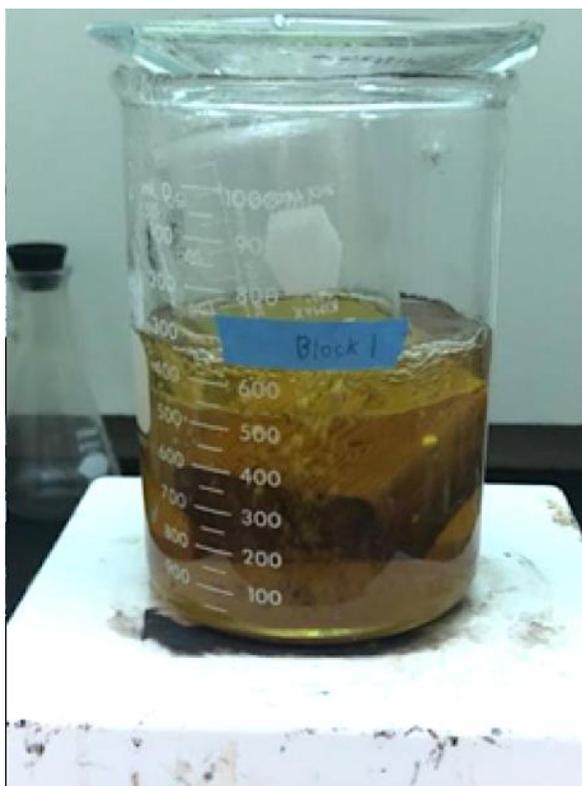
Figure 2.1: Block 1 solution after 3 hours of cooking. Note the color of the solution bath. The color of the liquid and block changed as more lignin and hemicellulose was extracted.

The Beer-Lambert Law was used to determine the amount of lignin removed from each block,

starting with block 3, during the densification process. The lignin quantification was carried out with use

of a Cary 800 UV-viscometer. All samples had to be diluted 10 times due to the high concentration of

lignin present within the solution. The concentration of lignin within the samples was calculated using the

following equation:

$$A = \varepsilon c l \qquad (1),$$

where A is the absorbance measured by the viscometer, ε is the extinction coefficient, c is the

concentration of lignin within the solution, and l is the length of the cuvette (Atkins and de Paula, 2002).

The blocks were then densified through compaction using a Carver hot press operated between 100 - 130°C and 1.7 - 5.1 metric tons (5 MPa – 14.8 MPa). The hot press was then set to the desired pressure for a period of 24 hours. Figure 2.2 depicts the compaction step for block 1 with an operating temperature of 100°C and pressure of 5 MPa (1.7 metric tons for the thesis) for a period of 24 hours. Table 2.1 summarizes the changes in procedure for each block.
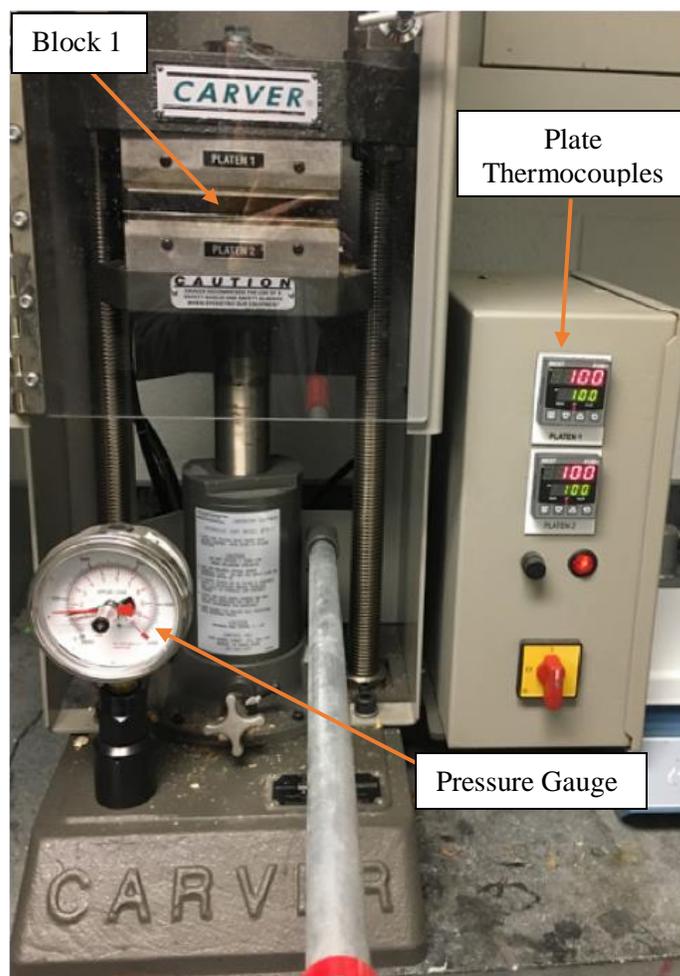
Figure 2.2: Carver hot press operated at 1.7 metric tons and 100°C for a period of 24 hours. Used to prepare Block 1

Table 2.1: Block densification procedural modifications.

Block	Cook Time (Hours)	Water Baths	Dry Time (Days)	Force (Metric Tons)	Temperature (°C)
1	7	1	1*	1.7	100
2	7	N/A	N/A	N/A	N/A
3	14	5	1*	7.0	100
4	7	3	2*	5.1	130
5	7	3	2*	5.1	130
6	7	3	2*	5.1	130
7	7	3	2	N/A	N/A
8	7	3	2	N/A	N/A

*Block dried in vacuum chamber

Characterizing the strength of the wood involved use of an ASTM D638 tensile testing equipment. Samples were cut to a thickness of 0.721 cm and the lengths of the samples were 6.710 cm for the untreated sample and 5.914 cm for the densified sample. The sample was clamped in the apparatus as shown in Figure 2.3. The block was stretched at a rate of 1.1 cm/min.

Figure 2.3: Untreated spruce wood sample with a thickness of 0.721 cm and length of 6.710 cm clamped in the ASTM D638 tensile strength equipment prior to experimentation.

The tensile strength factor was calculated by calculating the ratio between the untreated sample and the treated sample, depicted in equation (2).

$$T_F = \frac{T_{Tr}}{T_{Un}} \qquad (2),$$

where T_F represents the tensile strength factor, T_{Tr} is the tensile strength of the treated sample at failure, and T_{Un} is the tensile strength of the untreated sample at failure (Ajji, 2006).

2.2 Polymerization of HEMA Monomer

Three wood samples were created for each of the following wood preparation methods: natural (control), chemically treated, chemically treated and densified. These samples would first be placed in a water bath to determine the mass increase after two days. The samples were then transferred to an alcohol bath consisting of either methanol, ethanol, or 1-propanol. Samples 1-3 were the control samples, samples

4-6 were chemically treated but not compressed, and samples 7-10 were chemically treated and compressed. Table 2.2 summarizes this information.

Table 2.2: Summarization of sample type and location for alcohol baths.

Methanol	Ethanol	1-Propanol
1	2	3
4	5	6
7	8	9

Key	Category
	Untreated, Uncompressed
	Treated, Uncompressed
	Treated, Compressed

The blocks were placed in the alcohol solution for one week before being moved to the next solution. After the first bath, the water content of the solution was analyzed using a Mettler Toledo DL32 Karl Fischer Coulometer.

Samples 1 and 7 were selected to undergo monomer impregnation and polymerization using gamma irradiation. These samples were selected because methanol was able to remove all the water present within the block after water bath treatment. To prepare for the monomer irradiation step, the blocks were placed in test tubes containing HEMA monomer for two weeks. Afterwards, the samples were transferred to a new test tube, under vacuum, to be sealed off. The experimental set-up for sealing the test tube is pictured in Figure 2.4. Methanol vapors were reduced by placing the bottom of the test tube in liquid nitrogen until the test tube was properly sealed.
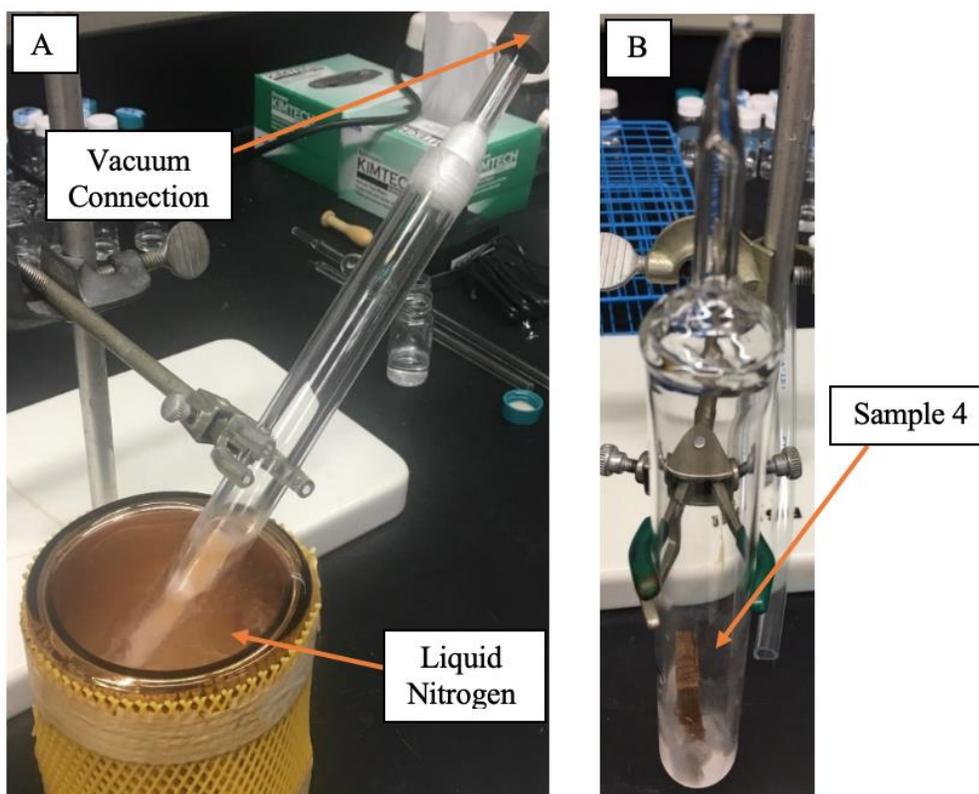
Figure 2.4: Vacuum sealing the sample in a test tube to prepare it for irradiation. A) Test tube hooked up to the vacuum source with the block submerged in liquid nitrogen to reduce methanol vaporization. B) Fully sealed test tube with sample.

A Co60 gamma ray irradiation source was used to polymerize the monomer within the sample. A dose of 50 kGy was applied to each sample. To achieve this dosage, the sample was exposed to the radiation source for 20 hours at a rate of 2.5 kGy/hr. The following equation was used to calculate the polymer loading of the samples:

$$PL\ (\%) = \frac{(M_{Wood} - M_{WPC})}{M_{Wood}} * 100 \qquad (3),$$

where M_{Wood} is the initial mass of the wood prior to treatment and M_{WPC} is the mass of the wood after irradiation polymerization (Ajji, 2006).

A water resistance test was conducted after the polymerization reaction to test the water resistivity of the irradiated samples. The blocks were placed in a test tube of water for 48 hours and the

mass percent increase was recorded. The water resistance of the densified, irradiated sample was then

compared to the water resistance of the densified sample.

Chapter 3

Results and Discussion

Spruce wood, a softwood found naturally in Pennsylvania, was used as a low-quality option for performance improvement. Eight blocks were created from a single plank of spruce wood and would be used for a variety of tests, including the densification of the wood and irradiation of a monomer impregnated within the wood. Blocks 1, 3, 4, 5, and 6 were the only samples to be chemically treated and densified. The water bath for block 2 fully evaporated, resulting in a charred block. Blocks 7 and 8 were processed, but not compressed. Block 4 was later used to develop the irradiation portion of the experiment.

3.1 Block Densification

The eight blocks underwent various densification procedures to determine the best preparation method. The processing procedure for each block is summarized in Table 2.1 and the results for the successfully densified blocks, 1 and 4, are summarized in Table 3.1. The errors encountered with the other samples will be discussed in this section.

Table 3.1: Thickness and density data for Blocks 1 and 4.

Sample	Thickness (BC) (cm)	Thickness (AC) (cm)	Density (BC) (g/cm)	Density (AC) (g/cm)	Density Increase (%)
1	1.550	1.250	0.503	0.672	34
4	1.540	0.686	0.490	1.16	137

Block 1 was created by following the steps outlined in the methods section of the Nature article. The block was cooked in a 2.5 M NaOH and 0.4 Na_2SO_3 solution for seven hours and rinsed in one water bath. A pressure of 5 MPa was applied to the block for a period of 24 hours as outlined in the Nature article (Song, et al, 2018). The equivalent 1.7 metric tons was applied to block 1 for a day. The density of this block had increased from 0.503 g/cm^3 to 0.672 g/cm^3. The block had increased in density slightly, but not to the expected extent (1.30 g/cm^3) (Song, et al, 2018).

The procedure was then modified to attempt to achieve this result for the next usable block, sample 4. For this sample, the number of water baths was increased to three to extend the delignating process as it was believed that one bath was insufficient. The operation of the hot press was also modified for this sample because 5 MPa did not densify the sample enough. The force applied to the sample increased by about 1 metric ton until the sample no longer visibly compressed. The final force, maintained for 24 hours, was 5.1 metric tons, which has the equivalent pressure of 14.8 MPa. The temperature of the hot press was increased to 130°C, ensuring any bound and free water would evaporate from the wood. The density of the block had increased from 0.490 g/cm^3 to 1.16 g/cm^3, which is 2-fold. The expected change in density was 3-fold, increasing from 0.43 g/cm^3 to 1.30 g/cm^3. This discrepancy may have occurred because spruce wood was used in the development of this thesis as opposed to use of redwood or pinewood used in the Nature research (Song, et al, 2018). Figure 3.1 (A) depicts blocks 1 and 4 with an untreated reference block. Note the change in thickness, where the density in block 1 increased by 34% and the density in block 4 increased by 137%.

Figure 3.1: A) Chemically treated and densified blocks measured against the reference block. B) Same blocks pictured in (A) after an 8-month period.

Block 4 was left in a drawer for eight months and warped. Pictured in Figure 3.1 is an image of Block 4 directly after compression (A) and after the eight months (B). The warping was most likely caused by the change in humidity as the seasons changed. This warping highlights the importance of applying a protective coating around the wood to prevent water content changes within the wood over a long period of time. Perhaps coating the wood with a monomer and inducing polymerization would be enough, assuming the scratch resistance of the polymer is enough. The Nature article reports expansion in the densified wood, under humid conditions, but the samples that were painted did not expand. These results were reported after a 95% relative humidity test which was conducted for 128 hours (Song, et al, 2018).

The lignin extracted from the wood was measured using a Cary 400 UV-viscometer. Quantifying the amount of lignin removed to compare with successful samples creates a more reproducible result. To measure the lignin content from solutions, a reference sample was run initially to determine the wavelength absorbed by lignin. A sample containing 1 mM lignin was run for this purpose and is graphed as the reference in Figure 3.2. The reference sample had a peak present at 281 nm with an absorbance of 1.61. The extinction coefficient was calculated, and a value of 16.13 L/g·cm was obtained. This value

would be used for subsequent absorbance calculations. When testing the caustic solution and water baths, a sample was taken and diluted 10 times because the absorbance was too large to read from the graph. Figure 3.2 is the UV spectrum used to determine the lignin extraction for block 4. The results of the other blocks are summarized in Table 3.2.
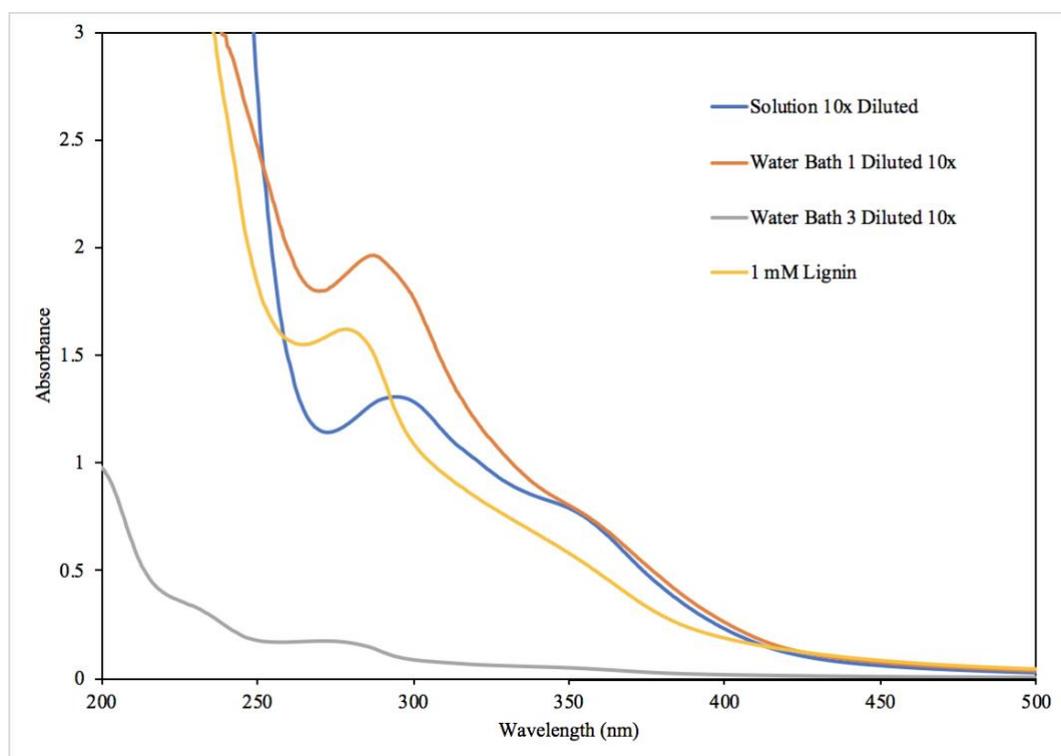

Figure 3.2: Absorbance data for quantifying the lignin within the cooking and bath solutions for block 4.

Table 3.2: Total lignin removed from each block.

Block Number	Lignin Removed (g)
3	2.1
4	1.3
5	1.7
6	1.9
7	2.0
8	1.3

Blocks 1 and 4 were the only blocks to be successfully densified because too much lignin was removed from other samples, causing cracks and other problems during the compaction step of the procedure. Some of these samples remained in the cooking solution for too long while others were exposed to a higher concentration of sodium hydroxide for an extended period. Block 3 remained in the caustic solution for 14 hours and was rinsed using five water baths for seven hours each. Prior to compression, a large crack developed along the growth direction of the block. An attempt for compression was made, but the block split in two during compression as the force was increased to 7 metric tons. Blocks 5 and 6 represent the consequences of using a highly concentrated cooking solution, pictured in Figure 3.3. Some water evaporated after a short period of time, reducing the total fluid level from 600 mL to 300 mL; thus, the concentration was estimated to reach a maximum of 3.8 M NaOH and 0.6 M Na_2SO_3. The standard chemical treatment concentration was 2.5 M NaOH and 0.4 M Na_2SO_3. This high chemical concentration caused cracks to from along the growth direction. The ideal amount of lignin extraction evaluated in this thesis is 0.42 g lignin per 10 g wood. Increasing the lignin extraction increases the chances of crack formation.

Figure 3.3: Chemically treated blocks 5 and 6. Both blocks were exposed to a higher concentration of sodium hydroxide than expected.

Block 4 was compacted again under a force of 5.1 metric tons for 12 hours to see if the original density of the block could be restored after warping prior to tensile strength testing. After compaction, the new thickness of the block was 0.721 cm, which is slightly thicker than the initial thickness eight months ago (0.686 cm). The thickness of the sample most likely did not return to the original value of 0.686 cm because the sample was pressed for 12 hours as opposed to 24 hours. The new density of the sample prior to tensile strength testing was 1.11 g/cm^3, which is a 4.31% reduction in density.

For the tensile strength test, a sample was cut from block 4 and a similarly sized sample of natural spruce wood was tested. The thickness of both samples were 0.721 cm and the lengths were 6.710 cm for the untreated sample and 5.914 cm for the densified sample. The test was performed by stretching the samples at a rate of 1.1 cm/min and the resulting stress-strain curve is depicted in Figure 3.4.
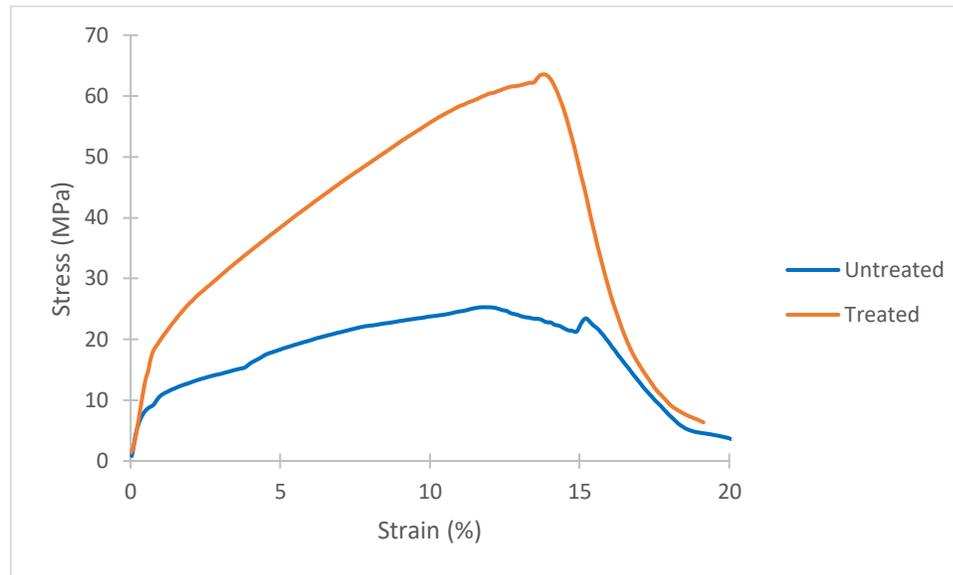
Figure 3.4: Stress-strain test performed on a treated and untreated spruce sample. The rate of tension was 1.1 cm/min on a sample with a thickness of 0.721 cm.

The tensile strength of the wood increased 2.51 times after chemical treatment and densification. The maximum stress the samples could handle increased from 25.3 MPa to 63.5 MPa. For the natural block, the initial failure (ultimate stress point) occurred at a strain of 11.8% where the stress was a maximum of 25.3 MPa, but the sample did not break until it reached a strain of 15.4%. The densified sample only experienced an ultimate stress point at a strain of 13.8% (63.5 MPa), which was enough stress to crack the sample. This data suggests that the densified sample is not as elastic as the untreated sample, however, both runs terminated around the same strain.

3.2 Polymerization of HEMA Monomer

Before the wood was converted to a wood-plastic composite, it had to be impregnated with monomer using a swelling agent. Nine samples were cut from natural spruce, the uncompacted but chemically treated block 8, and the densified block 4. The samples were placed in test tubes containing deionized water for 48 hours and the percent uptake in mass was calculated. Because there were three samples of each type of block, the average was taken and summarized in Table 3.3.

Table 3.3: Percent uptake in sample mass after wood samples were soaked in a water bath for 48 hours.

	Untreated, Uncompressed	Treated, Uncompressed	Treated, Compressed
Average (%)	32.5	55.7	58.5

The treated samples experienced the greatest mass uptake as expected because voids were created within the block due to the extraction of lignin. The treated, uncompressed samples absorbed slightly less water than the treated, compressed samples.

The samples were then transferred into test tubes containing one of the following alcohols: methanol, ethanol, or 1-propanol. The sample summary table can be found in Table 2.2 located in the materials section. The samples were left in covered test tubes for a week (168 hours) and tested for water content using a Karl Fischer Coulometer. These samples had to be diluted 10 times using 1 gram of solution per 9 grams of ethanol for the water content data to be accurate. The summary of water extraction, in percent, is summarized below in Table 3.4.

Table 3.4: Percentage of water extraction for natural wood, chemically treated wood, and chemically treated, densified wood.

Sample Type	Methanol	Ethanol	1-Propanol
Untreated, Uncompressed	100	100	100
Treated, Uncompressed	100	81.3	65.4
Treated, Compressed	100	88.5	72.6

Note: All numbers are reported as percentages.

The free water present within the samples soaked in methanol was extracted entirely, leaving the block full of methanol. As the molecular structure of alcohol increased in size, the percent extraction decreased, with exception to the natural samples where all three runs resulted in full water extraction. The size of the alcohol affects the diffusion into the wood block, as expected.

Wood samples soaked in the methanol solution were tested for polymer loading due to the increased success rates using methanol as a swelling agent in previous experiments (Ali and Khan, 1992). The natural wood sample and treated, compressed sample were placed in test tubes containing 100% HEMA monomer for two weeks. The samples were then irradiated with a dosage of 50 kGy, which took place over a 20-hour period. A previous experiment utilized acrylamide monomer and varied the irradiation dosages between 15 and 100 kGy. The researcher concluded that increasing irradiation dose positively affects PL but can negatively impact the mechanical properties of the wood (Ajji, 2006). A 50 kGy dose was used with this in mind.

The polymer loading of the sample was calculated using equation (2). The PL of the untreated sample was 127% and the PL of the treated, compressed sample was 95.9%. The decrease in polymer loading for the densified sample can be attributed to the decrease in monomer loading due to the cellulose reestablishing hydrogen bonds after the water was extracted. During the wood densification process, the blocky organic molecules (lignin) are extracted, leaving behind polar, straight chained structures

(cellulose). Lignin acts as a binding material, connecting cellulose and hemicellulose throughout the microstructure and creating a rigidity within the wood. Water can penetrate deep into the wood because it is a highly polar and relatively small molecule, compared to HEMA which is somewhat polar (due to the hydroxyl group), but is relatively large in size. Once the hydrogen bonds between cellulose chains reestablish themselves, the volume between the chains decrease, further decreasing the possibility of a large molecule absorbing deep into the wood.

To conclude the induced polymerization experiment, a water resistance test was conducted on the wood samples to determine if there was any reduction in water absorption for the samples. The test was conducted over 48 hours by placing the two samples of irradiated wood in deionized water test tubes. The untreated sample absorbed 14.3% of its initial mass. In earlier trials, the mass of the untreated blocks increased by 32.5%, on average. The treated and compressed sample mass increased by 33.5%. Before polymerization, the wood absorbed an average of 58.5% of its mass in water. The reduction in the water absorption for these samples is likely due to the formation of a polymer matrix which forms in the voids within the wood. The purpose of the induced polymerization is to further fill the voids within the block to prevent the diffusion of water into the wood to prevent warping (as seen in Figure 3.1) and wood decay, which is important when it comes to maintaining the integrity of a material.

Chapter 4

Conclusion

The goal of this thesis was to further characterize the material properties of spruce wood for use in construction. Characterization of these materials provides engineers with invaluable information to determine the optimal material for specific applications. It was found that by extracting 0.42 g of lignin per 10 g of wood sample, the density of spruce wood can be increased to 1.16 g/cm^3. In order to increase the density to this extent, the wood must be pressed at a pressure of 14.8 MPa and at a temperature of 130°C to be sure water present within the sample has evaporated.

The procedure developed for impregnating and irradiating the HEMA monomer resulted in a 95.9% polymer loading and a reduction in water resistance for the densified wood sample. The compacted wood created using the modified procedure absorbed 58.5% of its weight in water before monomer treatment and the water absorption in the block was reduced to 33.5% after monomer treatment. It was also shown that the densified wood is susceptible to warping under variable humidity, proving the necessity of a coating to protect the wood against moisture changes. There are a few methods readily available for protecting the wood against such conditions, such as coating the wood with a surface coating of paint. Irradiating the wood with a monomer or inducing polymerization of a monomer coating on the outer surface of the wood are also potential areas of focus for other experiments. Future experiments could test the reliability of each of these methods, denoting the strengths, weaknesses, and challenges for each of the methods.

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ANTHONY CALLO

EDUCATION

The Pennsylvania State University, Schreyer Honors College, University Park, PA
B.S. in Chemical Engineering with Honors   *May 2019*

EXPERIENCE

Research Experience Research Assistant, Department of Chemistry   *April 2018 - Present*
Professor: Dr. Bratoljub Milosavljevic
Engineering wood to improve the mechanical properties through densification and wood-plastic composite formation.
- Designing and testing new procedures to impregnate monomer into wood samples.
- Analyzing the effects of densification and polymerization treatment through strength tests.

Research Assistant, Department of Chemical Engineering   *September 2017 – April 2018*
Characterized the solubility of LDPE films using vapor solvents through gravimetric and pressure decay methods for Dow Chemical Company and Merck.
- Adjusted experiments to improve data collection accuracy and improved experimental procedures.
- Trained student researchers to use the pressure decay and gravimetric experiments.

PRESENTATONS/PUBLICATIONS

Penn State Poster Presentation, Making Wood Stronger than Steel, April 25, 2018