Comparisons of Heat Treated Wood to Chemically Treated and Untreated Wood in Commercial Usages

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Wood 493

A Report Submitted in Partial Fulfillment of the Requirements for the Degree of Bachelor of Science in Wood Products Processing

In

The Faculty of Forestry

The University of British Columbia

April 12th, 2013
Abstract:

Methods of heat treating wood for improved properties have been studied and developed for a long time. However, it was not until recently that heat treated wood has started being commercialized and sold on the market. The attention towards heat treated wood is caused mostly by public and legal demand for a more environmentally safe method of wood protection. Currently, most methods of preserving wood are done by chemical treatment using many kinds of chemicals, but the chemicals can cause harmful effects to humans and to the environment. Heat treating methods do not apply any chemicals within its process and can be considered to be environmentally safe. Many consumers who buy wood products are still unfamiliar with the qualities of heat treated wood and should know the differences it has before deciding what to use in their projects. The main points a consumer would be concerned with in determining whether to use heat treated wood is in its durability, physical mechanical properties, environmental impact, and economic feasibility. In general, heat treated wood is good green material against decay and has high dimensional stability, but certain strength properties are lacking. Therefore, for commercial usages such as flooring and decking, heat treated wood is superior to other wood alternatives. In this essay I will compare the advantages and disadvantages that heat treated wood has over chemically treated and untreated lumber when used in most timber structure applications common to normal homeowners.
# Table of Contents:

Abstract: ........................................................................................................................................... i
Table of Contents: ............................................................................................................................. ii
Table of Figures: ............................................................................................................................... iii
1.0 Background: ............................................................................................................................... 1
   History of Wood Preservation: ....................................................................................................... 1
   1.2 Heat Treating Process .............................................................................................................. 2
      1.2.1 ThermoWood Process .................................................................................................... 3
      1.2.2 Plato-Process .................................................................................................................. 3
      1.2.3 Retification Process ........................................................................................................ 4
      1.2.4 OHT Process .................................................................................................................. 4
   1.3 Commercial Use Applications .................................................................................................. 5
2.0 Durability of Wood: .................................................................................................................... 6
   2.1 Degree of Decay Resistance in Different Wood Types ........................................................... 6
3.0 Mechanical and Physical Properties: ......................................................................................... 7
   3.1 Load Strength .......................................................................................................................... 7
   3.2 Dimensional Stability .............................................................................................................. 8
   3.3 Color and Smell ..................................................................................................................... 9
   3.4 Ease of Machinability and Workability .................................................................................. 10
   3.5 Weathering Resistance .......................................................................................................... 10
4.0 Environmental and Health Issues: ............................................................................................. 11
   4.1 Environment .......................................................................................................................... 11
   4.2 Human Health ....................................................................................................................... 12
5.0 Marketability: ............................................................................................................................ 13
   5.1 Future Prospects for Heat Treated Wood ............................................................................. 14
6.0 Conclusion: ................................................................................................................................. 15
Bibliography ...................................................................................................................................... 16
Table of Figures:

Figure 1: Treatment Phases with Temperature over Time (Thermowood®, 2003) ........................................... 3
Figure 2: Changes of the impact bending strength of *Pinus sylvestric* after treatment compared to untreated controls. (Finnish ThermoWood Association, 2003) .................................................................................. 8
Figure 3: Variations in wood color with varying treatment times of 0 (A), 2 (B), 6 (C), and 8 (D) hours. (Srinivas & Pandey, 2012) ......................................................................................................................... 9
Figure 4: ThermoWood sales production in 2001-2007 with estimate for 2008. (Ala-Viikari & Mayes, 2009) .................................................................................................................................................... 13
1.0 Background:

Heat treated wood is one of the newest treated products introduced into the wood products market and is quickly gaining recognition by home owners. It is produced by an environmentally friendly treatment process that alters the properties of the wood. One of the main reasons that wood undergoes heat treatment is to modify its properties so that it has higher durability and dimensional stability that is ideal for applications that are subject to moisture and weathering effects. When untreated wood is exposed to moisture from the surrounding environment, it will eventually start decaying due to wood rot fungi, which attacks wood by breaking down its biological and chemical components that can. “The most common species used in heat treatment are pine, spruce, birch, and aspen, but all species of wood are possible to heat treat.” (Syrjänen & Oy, 2000).

History of Wood Preservation:

The practice of modifying wood to give better durability has been around almost as long as ancient civilizations have been using wood. Many different methods of wood preservation were discovered and revised over long years by trial and experimentation. Natural preservatives such as oil derived from plants were one of the earliest to be used. “Wood preserved with natural substances usually showed hydrophobic properties” (Hyvönen, Piltonen, & Niinimäki), which slowed the effects of rot fungi by limiting the amount of water that is necessary for fungi to grow. Chemical treatments of wood were later developed as a response to satisfy the demand for decay resistant wood for telephone poles and railways during the industrial revolution. Chemical treatments proved to be very effective at improving the durability of wood due to the fungicidal properties of the chemicals. However, as concerns over environmental and health impacts became more prominent in the world, more studies and experiments were conducted on wood protecting chemicals. Information of some of the harmful effects they pose was published and the government put restrictions and regulations on the use of the chemicals. This caused development of heat treated wood industry. The first known date for when heat treatments of wood is in the early 1900’s. Most of the studies done at that time were small scale (Johansson, 2008). It was only until the past few decades that heat treated wood has become produced at an industrial scale in which consumers can easily purchase.
1.2 Heat Treating Process

Currently, there are many types of heat treatment processes developed to get the same end benefits. These treatments all have one thing in common, in which the treatments involve the degradation of mostly the hemi-cellulose within wood under high temperatures in the range of 160-260 degrees Celsius. The differences in treatment processes “are to be seen in the process conditions (process steps, oxygen or nitrogen steaming, wet or dry process, use of oils, steering schedules etc.)” (Militz, 2002) Some of these processes can limit the level of oxygen inside the kiln to near zero by filling the treatment chamber with nitrogen or steam to prevent wood from combusting under high temperatures. Other processes can use oil as a medium to transfer heat more efficiently and also limit oxygen in the system. Each treatment process requires different optimization in their treatment phases for different wood species as the properties of each species differ. The different types of heat treatment processes that have been developed thus far include the Thermo Wood process from Finland, Plato-process from the Netherlands, Retification process from France, and OHT (oil-heat treatment) process from Germany. (Militz, 2002).
1.2.1 ThermoWood Process

Generally, there are three phases in the Thermo Wood heat treatment process as shown in Figure 1. The first phase consists of steady increases in temperature to dry lumber to nearly zero moisture content in preparation for the next phase. It is best not to start the treatment process with lumber that has high moisture content. The first phase is a high temperature drying phase where the wood can split and check from excessive drying. The second phase happens after drying is completed, and the temperature within the kiln is gradually increased to the level required for wood modification. The time and temperature the wood stays inside the kiln at this phase varies depending on wood species and the degree of modification requested. The third and final phase is for cooling the wood, as well as restoring the moisture content to acceptable levels of over 4% that are required for end use. Otherwise, defects will form as the wood absorbs moisture from the air.

![Figure 1: Treatment Phases with Temperature over Time (Thermowood®, 2003)](image)

1.2.2 Plato-Process

The Plato-Process primarily consists of two stages with an intermediate drying phase. The first step involves treating green or air-dried wood at temperatures between 160-190 degrees Celsius for four to five hours under increased pressures. The wood is then dried to a low moisture content of below 10% using conventional methods taking 3 to 5 days. The second stage heats the wood again at 170-190 degrees Celsius for a final curing step of 14-16 hours. The process times for each step vary with differing wood species, thickness, and shape. (Ruyter, 1989).
1.2.3 Retification Process

The process starts with perfectly dry wood which can be obtained by going through an intense drying phase of 160-180 degrees Celsius. Next, the temperature within the kiln is raised to a temperature of 200-240 degrees Celsius in a nitrogen atmosphere. Once the process reaches maximum temperature, the wood will be cooled down by sprinklers to return it to normal temperatures while retaining the properties of heated wood.

1.2.4 OHT Process

The OHT process is a heat treatment process that uses hot oil to circulate high temperatures around the wood stock in a closed vessel. Once the treatment process is finished, all of the oil is drained and pumped back into the stock vessel. For this process, the optimal temperature is at 220 degrees Celsius to obtain maximum durability while consuming the least amount of oil. However, it is possible to reduce the temperature slightly to reduce the amount of strength loss. The heating medium used in this process is crude vegetable oil. A minimum temperature tolerance of 230 degrees Celsius must be met for the type of oil used in this process.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Country</th>
<th>Heating Atmosphere</th>
<th>Temperature Range (°C)</th>
<th>Duration of Treatment</th>
<th>Dry Wood Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermo Wood</td>
<td>Finland</td>
<td>Steam</td>
<td>185-230</td>
<td>24 hours</td>
<td>No</td>
</tr>
<tr>
<td>Plato-Process</td>
<td>Netherlands</td>
<td>Steam, Heated Air</td>
<td>170-190</td>
<td>14-16 hours</td>
<td>No</td>
</tr>
<tr>
<td>Retification</td>
<td>France</td>
<td>Nitrogen</td>
<td>200-240</td>
<td>-</td>
<td>Yes</td>
</tr>
<tr>
<td>Process</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OHT Process</td>
<td>Germany</td>
<td>Crude Vegetable Oil</td>
<td>180-220</td>
<td>18 hours</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Table 1: Comparison between different heat treatment processes
1.3 Commercial Use Applications

Wood has been used to make various products for a very long time. Examples of these wood applications in households include flooring, decking, furniture, window and door framing, and siding. All of these end uses are susceptible to decay from exposure to moisture and require protection. For commercial wood applications where exposure to moisture can commonly occur, the degree of effectiveness against fungi that heat treatment provides is more than sufficient and consumers should be satisfied with the overall results. Using some species of wood that naturally have higher durability may be considered as an alternative by the consumer, but would be limited in the selection of wood species available. Chemically treated timber is generally not used in commercial wood applications except for areas that have low risk of human exposure. However, heat treating cannot be used for wood applications in contact with the ground. Other methods of wood treatment such as applying chemical preservatives like Chromated Copper Arsenate (CCA), or chemical modification like wood acetylation are better as a method of wood preservation for ground contact uses (Johansson, 2008). Therefore, using chemically treated wood on applications like fence posts and roofing is still an acceptable and logical choice. Some of the properties that are favored in specific commercial end usages are listed in Table 2.

<table>
<thead>
<tr>
<th>End Use</th>
<th>Moisture Contact Level</th>
<th>Need for Load Strength</th>
<th>Need for Dimensional Stability</th>
<th>Need for Color Stability</th>
<th>Need for Surface Hardness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flooring/Decking</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>Indoor Furniture</td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Outdoor Furniture</td>
<td>Medium</td>
<td>Medium</td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>Window/Door Frame</td>
<td>Medium</td>
<td>Low</td>
<td>Medium</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Siding/Cladding</td>
<td>High</td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
</tr>
</tbody>
</table>

Table 2: Wood End Uses and Their Level of Required Properties
2.0 Durability of Wood:

One of the biggest problems with using wood as a building material is that it decays. Untreated wood can easily lose its mechanical strength from the breakdown of the wood compounds that wood is made of. “There can be considerable losses in strength before decay characteristics are visually evident”. (Eriksson, Blanchette, & Ander., 1990) The breakdown of wood, also known as decay or wood rot, occurs when microscopic fungi attack wood by releasing enzymes to break down and absorb the biological cellular components of wood such as cellulose, hemi-cellulose, and lignin. The only three things fungi need to survive and grow are water, air, and a food source. Complete lack of one of these three necessities will effectively stop fungi from doing any damage. Untreated wood products that come in contact with high levels of water moisture will easily attract unwanted decay and mold. That is why methods of increasing wood’s resistance to fungi are being studied and developed. Currently there are many methods of preventing wood decay including applying natural and chemical substances to the surfaces of wood. (Eriksson, Blanchette, & Ander., 1990).

2.1 Degree of Decay Resistance in Different Wood Types

The degree of decay resistance in different wood products greatly varies between combinations of wood species and treatment methods. Some species are wood are already naturally resistance to decay from the extractives produced and deposited within heartwood as sapwood is converted to heartwood. This natural protection from decay is not perfect, as all species of wood will still rot and decay over time. Heat treatment provides a significant boost to the resistance of untreated wood. The reason why heat treating makes wood fungi resistance is because the process degrades the hemicelluloses. Once degraded, the hemicelluloses that are normally a food source for fungi becomes indigestible. Also, the equilibrium moisture content in heat treated wood is decreased during the heat treating process, which means that the wood will absorb less water under higher relative atmospheric moisture levels. Therefore, heat treated wood provides sufficient decay resistance for end uses that occasionally get wet. However, heat treated wood performs poorly in locations that are always in contact with water. Methods of wood preservation that involve chemicals are much more effective at preventing fungi attacks than heat treating methods, but are more suited to wood used in an industrial setting.
3.0 Mechanical and Physical Properties:

When considering what material to use in commercial applications, one must account for the necessary properties needed for wood products to maintain its shape or physical appearance for long periods of time. An issue that has always impeded the use of wood in buildings is the fact that its properties are variable. Each piece of timber is unique due to the fact that no two trees are identical. Inconsistencies in wood fiber along the length of timber make it impossible to make accurate calculations of the forces it can withstand. Therefore, a large error margin above the bare minimum of strength required from a material must be allocated in calculations to prevent any serious damage to the products and humans. People can use the strength data of raw wood materials to assess whether or not their product can be built structurally sound. Heat treatments of wood change the properties of wood to a degree where significant differences compared to untreated wood must be addressed. The main changes in properties a consumer would be concerned about are the load strength, dimensional stability, color and smell, hardness, and weathering resistance.

3.1 Load Strength

Wood is a building material that can theoretically hold large loads, if not for the large inconsistencies within the unique wood grain and defects present within a particular piece of lumber. Manufacturers and consumers who want to use wood in their products have to take into account various factors that might affect load strength, such as warping from the shrinking and expanding of wood due to changing moisture contents. During the lifetime of a building, moisture can accumulate in unprotected areas which can potentially weaken important wood components in a building. If left alone, it will dangerously increase the chance of structural failure over time due to the gradual sapping of mechanical strength from decay. Even if a building design with wood structures is approved for mechanical stability, there can be many unexpected events such as leaks which would call for experts to inspect for damages and repair where necessary. Currently, chemically treated wood is the only treatment that is plausible for constructing wood frame buildings. Since there are not as much negative effects of chemical treatment on the mechanical strength of wood, it is ideal for wood components that need to sustain large weights and are in contact with the ground such as beams. Heat treated wood on the other hand, is at a disadvantage in terms of its ability to hold loads. Since wood components are being degraded during the heat treatment process, some of its original mass is lost during the process. The strength of wood material in general has a “strong correlation with density”, and heat treated wood loses some of its density after treatment. (Finnish ThermoWood Association, 2003). Strength tests that have been conducted on heat treated wood show that there can be up to
a 30% decrease in yield strengths in their results depending on treatment method. (Viitaniemi & Jämsä, 1996). This can be a problem when considering the load bearing capabilities of heat treated wood for wood end uses as it is not as strong as untreated wood. With such a significant loss of material strength, the end use applications of heat treated woods are not recommended to be used as structural timber. An example of impact strength loss in heat treated wood is shown in Figure 2.

![Figure 2: Changes of the impact bending strength of Pinus sylvestric after treatment compared to untreated controls. (Finnish ThermoWood Association, 2003)](image)

3.2 Dimensional Stability

In general, heat treated wood loses some mechanical strength, but compensates with higher dimensional stability compared to chemically treated and untreated wood. When wood undergoes thermal treatment, the “hemi-cellulose components degrades, and the concentration of water-absorbing hydroxyl groups decreases”, giving it higher dimensional stability. (Finnish ThermoWood Association, 2003) This is very important for consumers who would use it in applications such as flooring where gaps in the space between panels expand as the wood warps. Increased dimensional stability reduces the effect of changing climates and seasons throughout the year and is greatly desired to maintain the appearance and uniformity of the wood products. This also applies for other wood applications where keeping the original shape of the wood is important such as common household wood products like doors, decking, and furniture.
However, as its dimensional stability is increased, the wood itself also becomes more brittle. Most species of heat treated wood is unable to withstand the same amounts of bending stresses in comparison to untreated wood. (Leijten, 2004).

### 3.3 Color and Smell

Some of the more noticeable changes that occur for heat treated woods are in the color and smell of the wood itself. All methods of heat treatment produce wood that are darker in color than its original, which is considered an improvement on aesthetics to many people who like the exotic appearance. Figure 3 shows the variations in color that can be achieved by manipulating the treatment times of the process. In general, the longer the treatment time, the darker the wood will become. However, some decay resistance is lost to shorter treatment times so consumers must decide how much is needed. Heat treated wood also produces a distinct “smell that can be characterized by a caramellish smell which is believed to be related to the releases of furfural”. (Militz, 2002). Even though these smells are not harmful, it can be disliked by some consumers. Fortunately, for consumers that dislike the smell, the heat treated wood can be surface treated to remove the smell from being emitted. The smell will also slowly dissipate over time to a degree where you can only smell it up close. (Finnish ThermoWood Association, 2003).

![Figure 3: Variations in wood color with varying treatment times of 0 (A), 2 (B), 6 (C), and 8 (D) hours. (Srinivas & Pandey, 2012)](image)
3.4 Ease of Machinability and Workability

Generally, the machinability of heat treated wood is no different than untreated wood. Sawing, milling, drilling, and sanding on heat treated wood are all as good as for untreated wood. However, consumers should be aware of the increased brittleness in heat treated wood. This calls for more careful handling of the wood itself as it can be easily damaged at the edge. On a side note, since heat treated wood is normally very dry, and wood dust created from machining can be a hazard in the workplace. An efficient dust collection system or dust mask is recommended in this case. (Finnish ThermoWood Association, 2003). The ease of gluing heat treated wood with adhesives are unchanged compared to untreated wood, except for water based adhesives which needs to account for drying times. (Finnish ThermoWood Association, 2003). For screwing, there needs to be some consideration for the material of the screws. Because hemi-cellulose produces acetic acid during the heat treatment process, there is some significant increase in corrosion of most metal screws compared to untreated wood. (Jermer & Andersson, 2005).

3.5 Weathering Resistance

For outdoor end uses, it is important to note the effects the weather has on wood products. Weathering effects are caused mostly by wetting and UV light and they usually cause discoloration and surface defects. In comparison to untreated wood, “treated wood does not attain better color stability, but more intense treatments can result in less weathering effects”. (Petutschnigg, Bächle, Zimmer, & Schnabel, 2009). Because “the resistance of heat treated timber against weathering is not changed largely when compared to untreated wood, this makes surface treatment with oils or paints necessary.” (Thermowood®, 2003). However, “wood, which is naturally hydrophilic, becomes hydrophobic after heat treatment and could generate important problems during varnish or paint deposition”. (Hakkou, Pétrissans, El Bakali, Gérardin, & Zoulalian, 2003). Since heat treated wood absorbs less water than untreated wood, it is harder to apply water-based finishes. Other finishes such as wax or oil are not affected greatly by the treatment process. “Decreased equilibrium moisture content of wood also improves stability, which decreases the cracking and flaking of surface coatings due to weathering. (Finnish ThermoWood Association, 2003). Overall there is not a big change in the weathering resistance of heat treated wood.
4.0 Environmental and Health Issues:

Over the last few decades, the importance of reducing human impact on the environment to a minimum has been rapidly increasing. (Gérardin, Pétrissans, Pétrissans, Gelhaye, & Dumaçay, 2012). Public demand and government legislation have been pushing corporations to do more about the factors that damage and harm the environment. Using natural wood products in structures is being viewed as a green option as wood is a carbon sink. This means that wood is a material that decreases the amount of CO₂ that is circulating in the atmosphere since trees absorb carbon from the atmosphere to grow. Buildings that use wood in its construction will usually last many decades, sequestering the carbon inside the wood material and preventing it from returning back into the atmosphere. Heat treated wood the same amount of impact on the environment in its life cycle as untreated wood. The only addition to the impact is the extra heat energy and steam required for the treatment process. (Finnish ThermoWood Association, 2003). Therefore, heat treated wood can be disposed of like any other untreated wood product.

4.1 Environment

In comparison to other methods of treating wood, heat treatment has an advantage in terms of being environmentally friendly and effective. Some methods of increasing wood decay resistance involve applying substances to the wood that could cause environmental or human harm depending on the type of treatment. For example, the preservative creosote, which is often used for railroad pilings and utility poles, can cause problems during disposal at the product end of life. Chemical treatments are often hazardous to the environment where the chemicals can leach into the environment and contaminate its surroundings, effectively impacting any animals or plants in the vicinity. Disposal of chemically treated wood at the end of life also requires controlled landfills sites where it can be properly handled. (Graf, Haas, & Böchzelt, 2003). The impact caused by heat treated wood at the end-of-life on the environment would be nearly the same as if it was untreated. The only difference would be any extra energy inputs like electricity, coal, or gas to get temperatures high enough to do the treatment process. (Thermowood®, 2003). Some gaseous emissions are also produced in the treatment process, which are all burnt to fulfill environmental regulations. In a sense, the color change of heat treated wood can be beneficial to the environment as a substitute for exotic wood species. Because the color of wood is thoroughly darkened during the treating process, a variety of colors can be produced from sustainable softwood species to resemble that of the unsustainable hardwood species. Consumers who love the darker shade of wood grain can now choose to be less impactful on the endangered forests where exotic wood species are harvested from.
4.2 Human Health

For commercial structural purposes where human exposure is high, it would be important to put very high emphasis any preservatives that may cause harm. There are some wood preservation methods that are hazardous to humans, many of which are chemical preservatives. Some countries like the United States and Canada have put restrictions on the use of chemically treated wood such as the commonly used CCA in locations with human contact. (Read, 2003). Since heat treated wood only requires high temperatures, there is no harmful chemicals or additives that a consumer would have to be concerned about when the wood is in use or disposed of. Compared to other wood preservatives that have no negative effects on human health, heat treated wood also provides extra benefits like color and dimensional stability, which can sometimes be a big advantage to consumers.
5.0 Marketability:

In general, heat treated wood is still relatively unknown to most people worldwide. It is mostly only in Europe and North America that heat treated wood is being produced and sold at high quantities. Heat treated wood is currently sold at a higher price than untreated wood due to its added value characteristics of higher decay resistance and dimensional stability. The price increases varies due to the duration and type of treatment but they generally cost one dollar more per board foot in contrast to normal lumber costs. (Peterson, 2010). The heat treatment not only provides protection against fungal attacks and weathering effects, but it also changes the color of the wood to a darker hue that can be compared to the more expensive exotic wood colors. The degree of darkening of the wood can be controlled by the treatment process, but may result in a loss of decay resistance or mechanical strength depending on how dark of wood the customers wants it. Many customers would be attracted to buying thermally treated wood as an inexpensive alternative to exotic wood species. Having higher dimensional stability also means that there would be less of a need for maintenance compared to untreated wood. To the common consumer, they would not have extensive knowledge of chemically treated wood. This may lead them to believe all chemical treated wood are bad for the environment or pose health risks. Markets for heat treated wood have developed considerably over the last few decades. Out of all the wood modifications currently being developed, heat treated wood is the most successful. In Figure 4, we can see that demand for heat treated wood is increasing and shows steady growth.

Figure 4: ThermoWood sales production in 2001-2007 with estimate for 2008. (Ala-Viikari & Mayes, 2009)
5.1 Future Prospects for Heat Treated Wood

As time passes, breakthroughs and new innovations will be introduced in the heat treatment industry. Improvements in the modification of physical characteristics can be further worked on to increase the effectiveness of the modification. Different and more efficient ways of heat treatment will also be developed to reduce the environmental impacts that are being caused, or to improve the properties of the wood. Examples of these improvements could be to make heat treated wood have a better ratio of increased decay resistance over density loss. There is also future potential for heat treated wood fiber being used as insulation as there is reduced thermal conductivity. (Ala-Viikari & Mayes, 2009). Better controls for raw material input can also lead to a significant improvement in surface performance of heat treated wood. Since the quality of wood is highly dependent on wood grain and defects, stricter selection of more homogenous raw materials with less knot distributions will give better performance.
6.0 Conclusion:

Heat treated wood is an excellent wood product that offers many advantages for several household wood products in comparison to untreated wood. These benefits include but are not limited to, increased durability against decay, reduced equilibrium moisture content, higher dimensional stability, reduced thermal conductivity, and darkening of the wood. The amount of disadvantages of heat treatment is minimal when compared to its advantages as the only general disadvantage present in heat treated wood is its increased brittleness and reduced load strength. Any home owners interested in furnishing their house with interior and exterior heat treated wood should be considering the differences these enhancements could do in place of other materials including untreated lumber.
Bibliography


