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Modeling moisture absorption and thickness swelling for oriented strand board (OSB)

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MODELING MOISTURE ABSORPTION AND THICKNESS SWELLING FOR ORIENTED STRAND BOARD (OSB)

By

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MODELING MOISTURE ABSORPTION AND THICKNESS SWELLING

FOR ORIENTED STRAND BOARD (OSB)

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The dimensional stability of oriented strand board (OSB) can be affected by processing variables. This study investigated the water absorption and thickness swelling of OSB based on its board layup, type of resin, resin content, and percentage of wax. The experiment data was measured inside an environmental chamber from oven dry (OD) conditions to 80% relative humidity (RH), and from OD to 90% RH. The results suggest that single layer boards and isocyanate resin provide greater dimensional stability to OSB than three layer boards or phenol formaldehyde resin. In addition, the water absorption and thickness swell data were effectively modeled by equations developed for wood fiber/polymer composites.

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CHAPTER I

INTRODUCTION

Oriented strand board (OSB) is an important material in the housing and construction industries. One challenge of working with OSB is its moisture properties. When dry, OSB has good mechanical strength, but at elevated moisture content it will lose strength. OSB must be carefully monitored in high temperature, high humidity areas such as the southern United States. Moisture has the same effect on wood composites whether it is absorbed occasionally, like rainwater, or gradually as in a high humidity environment. This research investigates the moisture absorption properties of OSB and the resulting effects on thickness swell.

The strength of OSB is straightforward. Much like wood, OSB has good mechanical strength when it is kept dry. As a construction material it is more environmentally safe then steel or plastics and can be produced economically. This has led OSB to be a preferred choice for housing construction as a sheathing product. The mechanical strength of OSB is reduced by elevated moisture levels. While direct contact with water from rain or the ground will quickly affect its moisture content, OSB will also absorb moisture from the atmosphere to reach equilibrium moisture content with its surroundings. The equilibrium moisture content increases as humidity increases – therefore a region's mean relative humidity can determine the in-service strength properties of the OSB. This research addresses two questions that arise from the problem of ambient atmospheric moisture:

1. How do the variables of OSB manufacture affect its moisture absorption?
2. How well can the moisture absorption and thickness swell of OSB be predicted by a model for wood fiber/polymer composites?

One common method to prevent moisture absorption in OSB is to alter how it is manufactured. Most researchers find more resistance to moisture absorption by increasing the resin content and wax content of the board.

The second part of this research involves modeling the moisture absorption and consequent thickness swell of OSB. Wood fiber/polymer composites were studied by Shi and Gardner (2006 a, b), whom developed a model capable of predicting mass and thickness changes over time. The same model was applied for this project to see if the equations could be used as a model for OSB.

CHAPTER II

LITERATURE REVIEW

Oriented strand board (OSB) serves as a valuable resource for construction. One of the biggest factors influencing its use is moisture absorption. Under wet conditions wood loses its strength, making it vital that wood and wood composites stay dry in use. Gaining means to predict how moisture is absorbed and causes swelling in OSB is the focus of this paper.

Moisture Absorption and Thickness Swelling of Wood Composites

Moisture absorption (MA) and thickness swelling (TS) in wood are well documented. Baileys *et al.* (2003) recognized the necessity to protect wood composites from moisture. She noted that with strand board, it is possible to insert a moisture and fungi resistant formula into wood strands prior to board formulation without negatively impacting mechanical strength. Other authors have shown similar results (Kirkpatrick and Barnes 2007, 2006a, 2006b, Barnes and Kirkpatrick 2005). Fan *et al*. (2006) included oriented strand board in a study of the long term movement of moisture through wood composites. The actual test size of samples was found to have a large effect on their relative creep behavior. Relative humidity (RH) had significant effects on the long term creep of OSB in regards to the number of RH cycles. Edge sealing also had a large effect on minimizing relative creep of the samples. Xu *et al*. (1996) measured the distribution of water absorption (WA) by oriented strand board. Images were taken using vertical density profiles. It was observed that the two face regions of the samples were responsible for more of the water absorption in the product. This fact points to the high density face layers causing increased absorption.

Moya *et al*. (2009) demonstrated the most noticeable change in moisture content or thickness swell occurred in the first week of sorption testing. The cyclic relative humidity testing was done with red pine OSB using a 3.5% isocyanate (pMDI) resin. Testing conditions for the samples were set at 20°C and 65% RH for equilibrium of samples before testing. Moya *et al*. (2009) tried three models to compare moisture content and thickness swell as a function of time: logarithmic, power law, and exponential. A power or exponential function provided the best fit. The authors employed ANOVA to compare end point values of two data sets, one with and one without bark added to the OSB. A comparison between charred and uncharred wood furnish showed no significant difference ($\alpha = 0.05$). Samples with charred bark added were found to have significantly lower moisture content and thickness swelling compared to samples without bark.

OSB was one of the materials tested by Garay *et al*. (2009) investigating performance at high levels of temperature and relative humidity. The recordings of TS and MA over time were less for samples that had been painted or sealed. It was determined that exposure time and staining or painting the OSB affected thickness swelling and moisture absorption. The author also noted that for OSB produced with a pMDI core resin and a phenol formaldehyde (PF) face resin there would be variation in the density profile, which would lead to variation in the physical properties.

Jong and Wu (2002) presented a study of three layer OSB, comparing swelling and bending properties based on variables which included resin content, flake alignment, and moisture content. A mathematical model was developed to predict linear expansion, and the predictions were compared with actual data. There was a curvilinear relationship between linear expansion and moisture content with a larger swelling rate at the lower moisture content ranges. In a study of wood strands, Cai *et al*. (2007) highlighted the effects of moisture absorption and thickness swell on pressed boards. Four types of wood strands were tested, including southern pine strands. The furnishes were either not hot pressed, hot pressed, or hot pressed and treated with PF resin. All the furnish treatments were formed into a randomly oriented panel, a single oriented panel, and a cross oriented panel. It was found that TS values in hot pressed panels were higher than those of strands that were not pressed. The water absorbing effect of the compression ratio of southern pine is offered as an explanation in lieu of the assumption that the application of resin will deter swelling in wood strands.

Del Menezzi *et al*. (2009) approached the issue of moisture absorption and thickness swell from another angle: post treatment hot pressing as a means to improve dimensional stability. The test material was commercially obtained OSB with a PF resin face and a pMDI core. OSB panels were pressed between 12 and 20 minutes at 190°C or 220°C. ANOVA was used for analysis of thickness swell, moisture absorption, time, temperature. They showed improved dimensional stability for the treated boards. The modulus of rupture of treated panels was lower following treatment, and no other physical properties were compromised. Han *et al*. (2005) looked into an alternative material in place of wood fibers to save on manufacturing costs. When Comrind sugarcane fibers were used in the core layer of OSB, less linear expansion and less thickness swell than standard OSB was found. The strands and Comrind were bonded with PF resin. Density profiles of the samples largely mimicked regular OSB.

Tackie *et al*. (2008a, 2008b) investigated the effect of density on thickness swelling of OSB. His focus was to develop a finite element model for OSB that could predict thickness swell. The model is based on a three dimensional density distribution for an OSB panel and used linear interpolation with degrees of freedom in the out-of-plane direction. For commercial panels tested, the model operated with an error of less than 10% for most tests. He demonstrated that areas of high density are more prone to thickness swell than areas of low density.

In a study on PF-bonded laboratory boards, Wu (1999) showed that resin content did not have a large effect on linear expansion of the OSB. Density was largely responsible for the results of linear expansion, MOE, and MOR. Wu and Piao (1999) related thickness swelling to internal bond strength loss of commercial PF-bonded oriented strandboard. A linear relationship between moisture absorption and thickness swell was found. Internal bond (IB) strength decreased with increasing thickness swell (TS). Sumardi *et al*. (2007) studied on the effect of board density and layer structure on the mechanical properties of bamboo oriented strandboard. The linear expansion of these samples was similar or slightly less than commercial OSB. The author noted that the alignment angle distribution of bamboo strands could be predicted with the von Mises distribution function. The findings of the study showed that a randomly oriented strand panel will exhibit more TS than single layer or three layer panels. Taylor *et al*. (2008) checked the properties of commercial "enhanced" OSB subflooring. The enhanced panels showed about forty percent less TS than standard OSB after 24 and 72 hours soaking. They showed similar mechanical properties to regular OSB, and were also susceptible to mold and fungal infection. The method of enhancement was not provided.

Wolcott and Shutler (2003) described how the panel formulation process for wood composites would collapse the cellular structure of the wood. Upon receiving moisture, the cell structure would recover causing thickness swelling in the wood and limiting the structural integrity. The article draws attention to the importance of controlling moisture in the preparation of wood composites. Van Houts *et al*. (2004, 2006) noted that the rate of water penetration was similar in both the surfaces and the edges of OSB. Interstrand voids within the OSB were the main route of moisture movement. Voids and low density areas largely contributed to the flow of moisture through OSB, allowing it to swell more easily. A silicone sealant was shown to inhibit moisture penetration in the wood product.

Modeling of Wood Composites

Recent work (Shi *et al*. 2000, Shi and Gardner 2006a, b, Shi 2007) models how the moisture absorption and thickness swelling process occurs in wood fiberboard and polymer composites.

A wood composite's maximum amount of moisture absorption may change based on its furnish. Shi *et al*. (2000) investigated wood fiber and polymer fluff to determine an equation to predict moisture absorption based on the density and the wood to polymer ratio. There was insignificant thickness swell associated with the wood fiber and polymer fluff composites, most likely due to the hydrophobic nature of the polymers. Shi and Gardner (2006a) discussed wood fiber/polymer composites further by looking into the hygroscopic thickness swelling rate. They discovered a significant relation between the thickness swelling rate and the density of the wood composite. There was some effect on polymer content but it relied on board density. The equation designed for use in determining thickness swell was a good fit to the data acquired in that research. Another study by Shi and Gardner (2006b) utilized the same equation for hygroscopic thickness swelling rate. The goal of this study was to test the equation in relation to temperature and relative humidity and to model how the hygroscopic thickness swelling of wood polymer composites were affected in an ambient environment. There was a strong, positive linear relationship between the temperature and the thickness swelling rate. The relative humidity had a weak relationship with the thickness swelling rate. In this study, the lower the swelling rate was, the better the model could predict it.

Following the investigation into wood fiber/polymer composites, Shi (2007) studied the diffusion coefficients for composites. His findings suggest that the diffusion model for wood fiberboard and wood fiber/polymer composites, based on Fick's second law, was not predictably accurate. Not surprising, higher temperature yielded a higher diffusion coefficient. Diffusion coefficients decreased with increasing relative humidity. Also, there was no relationship between the diffusion coefficients and the board density. Another study detailed two part equations for wood fiber/polymer composites under over saturated conditions (Shi and Wu 2008). The developed model accurately depicted the moisture absorption process. Larger moisture absorption coefficients were found at higher temperatures.

Jin and colleagues (2009) investigated uniform and conventional vertical density profiles of face PF resin strand boards that included an emulsified wax. They discussed two types of vertical density profiles (VDP), and mentioned manipulating the VDP in order to improve the modulus of elasticity. Water absorption of OSB samples decreased with increasing density. Thickness swell increased with increasing density up to 650 kg/m^3, beyond which the TS decreased. Uniform or conventional density distribution was not found to affect the WA or TS properties. Sorption isotherms were modeled and predicted by Wu and Ren (2000). In the case of a vertical density gradient, it was shown that a low density core layer of OSB had higher equilibrium moisture content (EMC) than the higher density face layer. Depending on the relative humidity, panel density was the largest factor in determining moisture absorption of an OSB panel.

Effect of Processing Variables

Resin Type

Sellers and Miller (2004) investigated resins made by combining tannins with PF resin. The wood strands used for the board manufacture were from southern pine species. The focus of the testing was on manufacture of panels and properties immediately after pressing. They found that the TS and WA values for tannin-PF mixes had similar or lower values than the PF control. Increasing resin binder solids by three percent also decreased the TS and WA values for tannins by as much as half. Brochmann *et al.*

(2004) studied influence of strand thickness and resin type (PF, pMDI) on properties of OSB. Resin type had a larger effect on the dimensional stability of the panels compared to the strand thickness. Thickness swell was minimized with a PF resin face and pMDI resin core. Some variables that were not accounted for in testing included the board pressing, surface density, and flake moisture content. Paridah *et al*. (2006) detailed improving the dimensional stability of multi-layered strand board through resin impregnation. The formulation of the boards used a low molecular weight PF resin (LPF), impregnated into strands, and a standard PF resin to bond the board. This led to a reduction in TS of about 20%. Mechanical properties such as internal bond were much lower than regular OSB but their values did increase with increasing LPF. Extending the press time for the boards led to high moisture resistance and more acceptable mechanical strength.

<u>Resin Content</u>

Linville *et al*. (2001) showed that increased resin content in OSB with decreased thickness swell for samples prepared with pMDI resin. They found that TS in composites can be controlled by minimizing either the density or the horizontal density distribution. TS was also minimized by increasing the pMDI resin content. The results also noted that TS increased linearly with increasing density.

<u>Wax Percentage</u>

Winistorfer *et al*. (1992) evaluated the performance of ten wax types and three wax furnish rates on the properties of pine strand board. The boards showed increased dimensional stability with increasing wax application rates. However, the performance of wax types was not considered statistically different, and no one type of wax was considered superior for the test.

Eckert and Edwardson (1998), in a study to determine the proper type of wax emulsion for OSB, showed that the performance of OSB improves as the wax addition rate is increased. They compared neat wax to wax emulsions and found that for the same amount of material added, an emulsion form provided more water absorption, thickness swell, and edge swell protection than neat wax. The emulsion wax decreased WA, TS, and edge swell linearly up to 0.9-wt. percent wax, after which the effects diminished.

CHAPTER III

METHODS AND MATERIALS

Board Preparation

The material used for research was southern pine oriented strand board. Target density for all boards was 623kg/m^3. The target thickness of all samples was 12.7 mm. The following pressing cycle was the same for all boards. The press closed in 60 seconds to 13.7 mm, and held at that position for 10 seconds. Then it was pressed to 12.7 mm and held there for 210 seconds, then 30 seconds for press opening. Platen pressure varied with board type and resin content but ranged from 6000 to 7000 kPa. The press temperature was 180°C.

Forty different board treatments were used. Variables included layup type, resin type, application rate of resin, and wax content. Layups for boards were either a single layer randomly oriented board or a three layer cross oriented board. There were two types of resin used: isocyanate resin at 2% base solids or phenol formaldehyde at 4.5% solids. Five different percentages of the base application rate of the two types of resin were included: 65%, 83%, 100%, 117%, 134%. The single layer and faces of the three layer boards used either pMDI or PF resins. The cores of three layer boards were either isocyanates or a phenol formaldehyde/isocyanate mix as this was found to improve dimensional stability. Wax addition rates were either 0.5% or 1.0%. All treatment variables are listed in Table 1. Each test board was pressed in a twenty by twenty inch panel (508 mm) and was then trimmed to measure eighteen inches (457 mm) square. After pressing all boards were hot stacked in an insulated thermal box in order to facilitate resin cure.

Table 3.1. Treatment variables for the oriented strand boards.

Board Layup	**Resin Base Rate (% solids)**	**Resin content**			**Wax %**
		% of base	**PF % solids**	**pMDI % solids**	
Single-layer Three-layer	Phenol formaldehyde (PF) (base = 4.5%) Isocyanate (pMDI) (base = 2.0%)	65 83 100 117 134	2.92 3.74 4.50 5.27 6.03	1.30 1.66 2.00 2.34 2.68	0.5% 1.0%
Total: 40 treatment combinations (2 x 2 x 5 x 2)					

From each test panel, a set of three two by two inch (50 mm^2) samples were sawn and used for testing. Before testing, all samples were edge coated with phenol-resorcinol resin.

Experimental Procedure

Samples were oven dried at 100.3°C for twenty-four hours prior to testing, then moved to a desiccator over $CaCl_2$ to cool. Initial measurements of weight and thickness were recorded after cooling, and following that samples were placed in an environmental chamber at 20°C and 80% relative humidity. The weight to the 0.1g and thickness to the 0.001inch (0.025mm) were taken at 0, 0.5, 1, 2, and 4 hours, then recorded daily until equilibrium was achieved. The chamber was raised to 90% relative humidity and matched samples were tested in the same manner. A typical plot of water absorption and thickness swelling as a function of exposure time is shown in Figure 3.1.

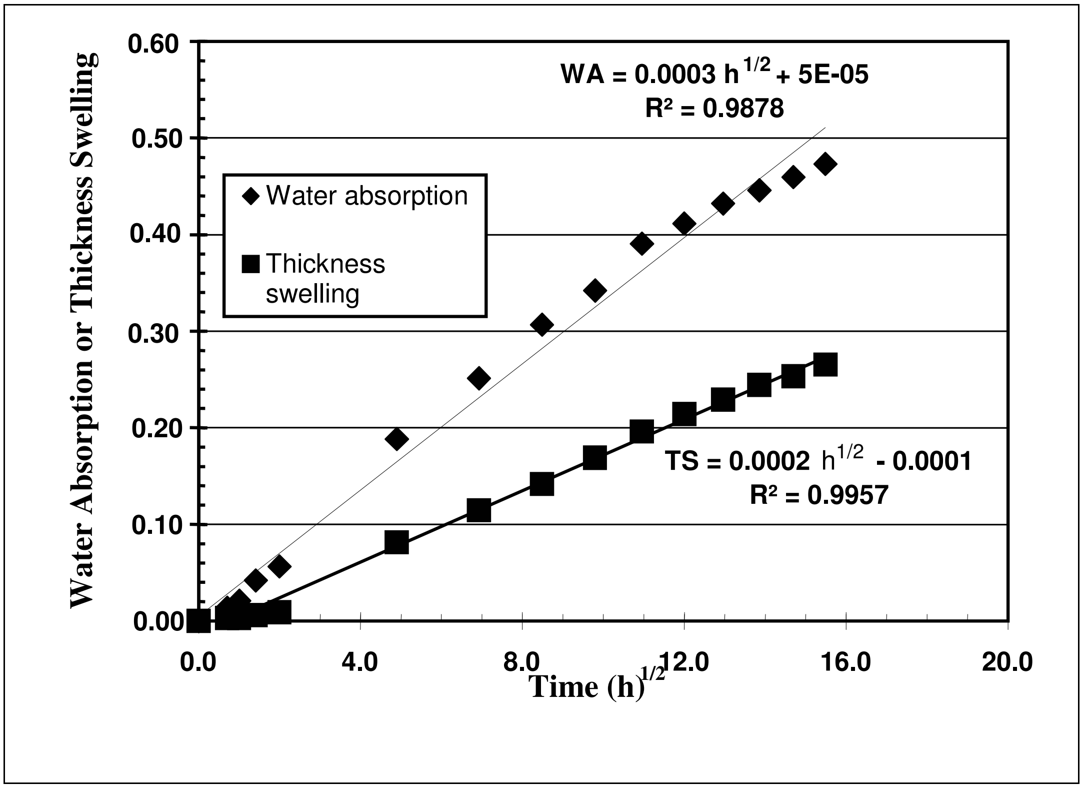


Figure 3.1. Typical plot of water absorption (WA) and thickness swelling (TS) vs. time.

Equation Modeling and Statistical Methods

The modeling utilized the equations of Shi and Wu (2009). The equation for moisture absorption was as follows:

$$WA(t) = 100 \cdot [(WA_\infty/100)(1-\exp(-k_{WA}t^{1/2}))]/[1 + (WA_\infty/100)\exp(-k_{WA}t^{1/2})] \qquad (3\text{-}1)$$

where:

$WA(t)$ = percent water absorption at time t;

WA_∞= equilibrium water absorption; and

k_{WA} is a constant.

The equation for thickness swell is:

$$TS(t) = 100 \cdot \{T_\infty/[T_0 + (T_\infty - T_0)\exp(-k_{TS}t)] - 1\} \qquad (3\text{-}2)$$

where:

$TS(t)$ = percent thickness swelling at time t;

T_∞= equilibrium thickness swell;

T_0 = thickness at oven dry condition; and

k_{TS} is a constant.

Equations 3-1 and 3-2 were placed in MATLAB (2007) software. The software produced the following values given the observed values of WA and TS over time:

WA_∞ or TS_∞ = equilibrium moisture absorption or equilibrium thickness swelling values

K_{WA} or K_{TS} = constants

R^2 = coefficient of determination (%)

Typical outputs from MATLAB are shown in Table 3.2. Statistical Analysis Software (SAS 2008) was used to determine significant differences between the treatment groups. Shared time values of WA and TS were retrieved from the last shared hour for each moisture exposure: 80% relative humidity used the time at 196 hours and 90% relative humidity used the time of 360 hours. Inputs were WA and TS for each test. Factors were layup, resin type, percentage resin, and percent wax. The test was an analysis of variance for a general linear model. Tukey's studentized range was used at an alpha value of 0.05, and the SAS program ranked the least square means of all treatments for their WA or TS at a given RH.

Table 3.2 Typical results from MATLAB software for three layer board, isocyanate resin at 100% application rate and 0.5% wax at 80% relative humidity.

	Change in mass from od (g)			Change in thickness from od (in).		
Sample #	1	2	3	1	2	3
Hours						
0	0	0	0	0	0	0
0.5	0	0.004184	0.004808	0.001984	0	0
1	0.004762	0.004184	0.004808	0.001984	0	0
2	0.009524	0.008368	0.009615	0.003968	0	0
4	0.014286	0.008368	0.014423	0.005952	0	0
24	0.042857	0.037657	0.043269	0.02381	0.015779	0.013917
48	0.057143	0.050209	0.057692	0.029762	0.021696	0.023857
72	0.071429	0.062762	0.067308	0.039683	0.025641	0.027833
96	0.080952	0.066946	0.076923	0.045635	0.031558	0.033797
120	0.090476	0.079498	0.086538	0.051587	0.037475	0.039761
144	0.095238	0.083682	0.091346	0.055556	0.04142	0.043738
168	0.1	0.087866	0.096154	0.059524	0.045365	0.045726
192	0.104762	0.09205	0.096154	0.063492	0.047337	0.049702
216	0.104762	0.096234	0.100962	0.065476	0.04931	0.05169
240	0.104762	0.100418	0.105769	0.06746	0.053254	0.053678
WA or TS	0.2013	0.2702	0.1896	0.539005	0.536767	0.53259
K or K_{SR}	0.0585	0.0367	0.06	0.012487	0.008986	0.00979
R^2	0.9923	0.9952	0.9962	0.992013	0.991602	0.994507

CHAPTER IV

RESULTS AND DISCUSSION

Investigation of the 80% relative humidity (RH) exposure was limited in scope, and equilibrium was not reached in all cases. Because of the non-equilibrium state for 80% data, time was extended for 90% testing.

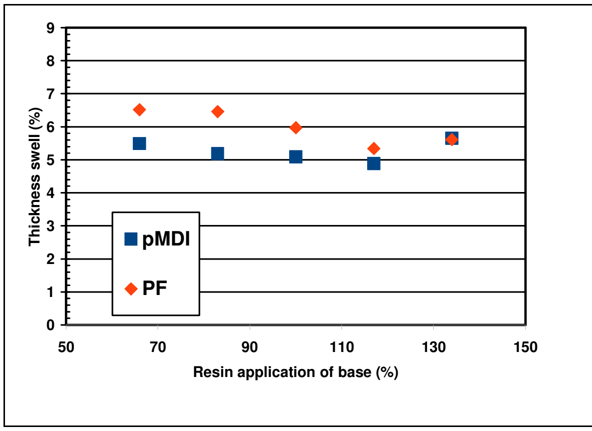
Most final recorded water absorption values for 80% RH averaged 10%. If graphs are extrapolated from the provided data, the percent WA is 25% lower than at 90%. The WA remained constant across both resin types, all resin contents, and either wax percentage. Thickness swell (TS) across all formulas was about 6%. Given uniform MC and TS across all formulas, 90% RH samples were used to determine most relationships.

Samples tested at 90% RH took almost 400 hours to reach equilibrium. For some samples that was not sufficient time. WA for all types of samples was 15% on average and average TS was about 10% in most samples.

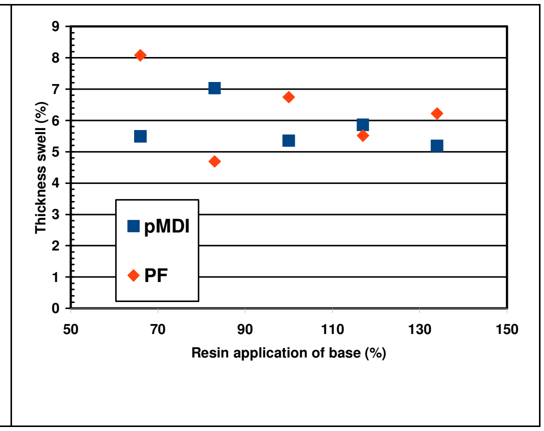
Effect of Processing Variables

Graphs were prepared for the relation of thickness swell or water absorption at 80% and 90% relative humidity over an increasing resin application rate for the remaining factors of the study. Single layer and three layer boards, pMDI and PF resin, and 0.5% and 1.0% wax application were the factors. For these graphs one treatment would vary with the others held constant.

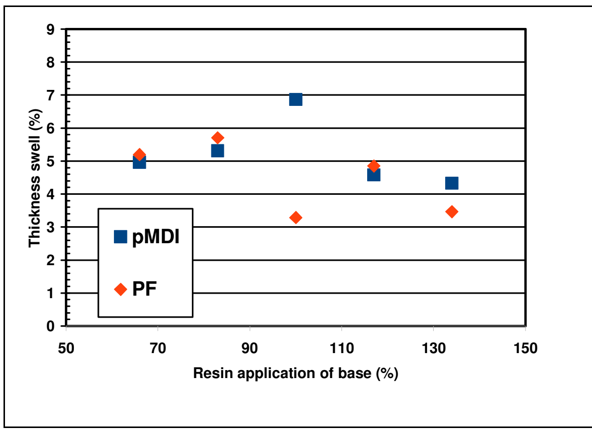
There were some graphs of thickness swell at 80% relative humidity that indicate general relationships of the factors of OSB. For instance, Figure 4.1a shows pMDI and PF resins in a slight decreasing linear relationship with increasing application percent of resin at 1% wax content. This implies that at a given resin loading, it will take a greater percent of PF resin at 4.5% base to equal the same amount of resistance provided by pMDI at 2.0% base. At 0.5% wax, no clear trend is evident (Fig. 4.1b). There is a unique trend for pMDI resin made with a single layer of flakes at both .5 and 1 percent wax (Fig. 4.1c, 4.1d). Optimum TS and EMC values are achieved at the mid-point resin addition rates which are not predicted for these ranges of application rates. The highest thickness swell was at 100% application. In contrast, the lowest point of TS for PF resin was at 100% resin content. These findings could represent the variation caused by statistically similar factors, or the absence of uniform density in the samples. These results may warrant further investigation.



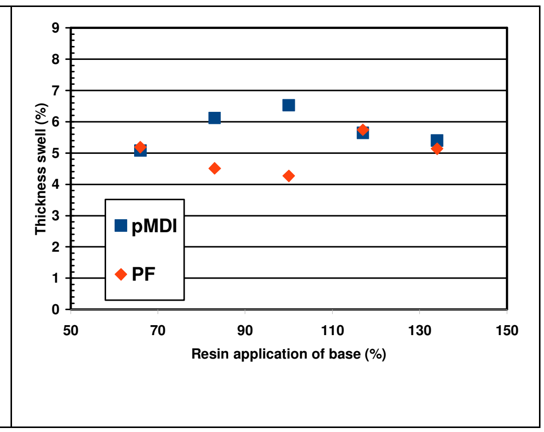
a. Three layer board type, 1% wax



b. Three layer board type, 0.5% wax



c. Single layer board type, 1% wax

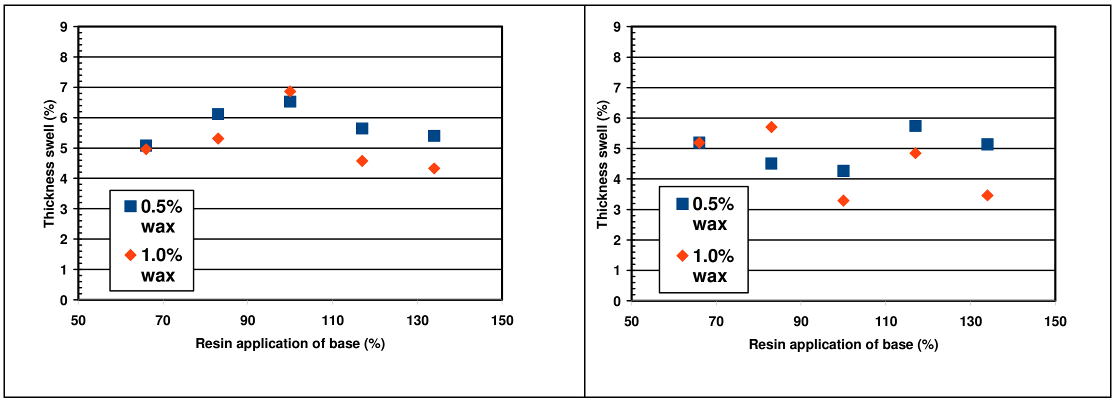


d. Single layer board type, 0.5% wax

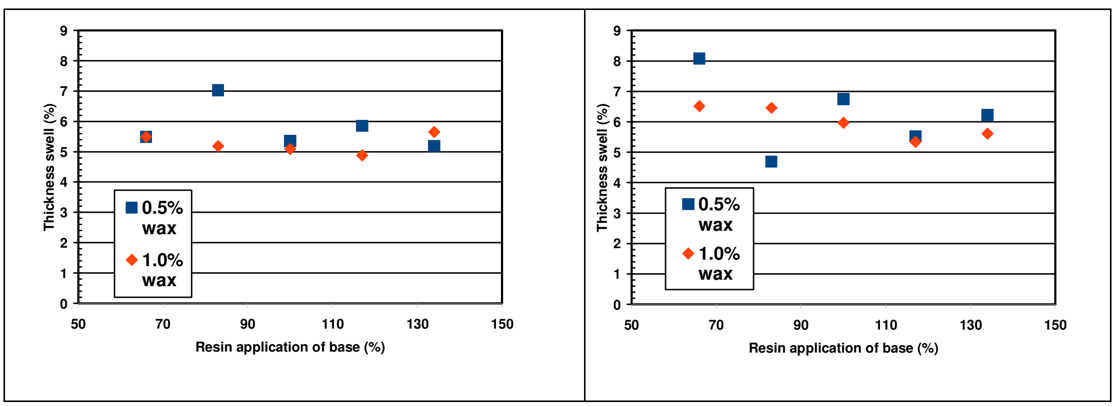
Figure 4.1. Effect of resin type on thickness swell of OSB at 80% relative humidity after 196 hours of exposure.

The effect of percentage of wax on thickness swell in OSB was expected (Fig. 4.2a, 4.2b). When holding other variables constant, an increase in wax generally led to a decrease in thickness swell. Disregarding noise, it appeared that for three layer boards there was no noticeable difference in thickness swell between the two addition rates of wax (Fig. 4.2c, 4.2d). more void zones from the crossed levels of strands in three layer boards, allowing moisture to more easily enter the wood more easily.

It appeared that for three layer boards there was no noticeable difference in thickness swell between the two addition rates of wax (Fig. 4.2c, 4.2d).



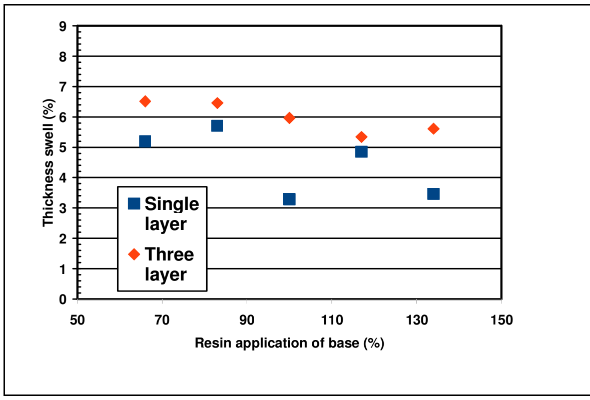
a. Single layer board type, pMDI resin b. Single layer board type, PF resin



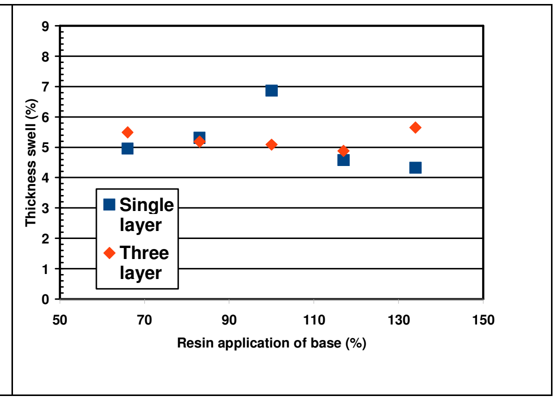
c. Three layer board type, pMDI resin d. Three layer board type, PF resin

Figure 4.2. Effect of wax on thickness swell of OSB at 80% relative humidity after 196 hours of exposure.

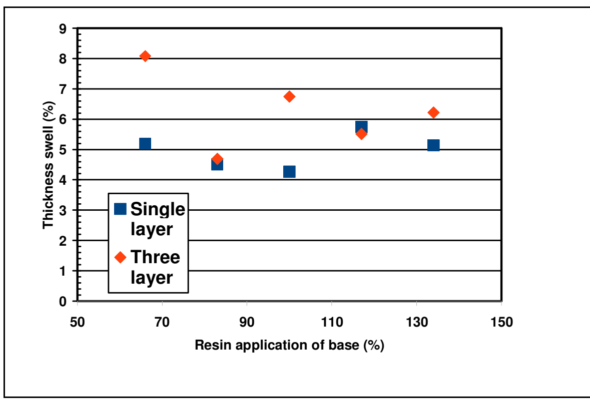
When board layup was compared, it was noted that single layer would swell less than similar three layer boards (Fig. 4.3a-4.3d). This can be explained since there are often more void zones from the crossed levels of strands in three layer boards, allowing moisture to more easily enter the wood.



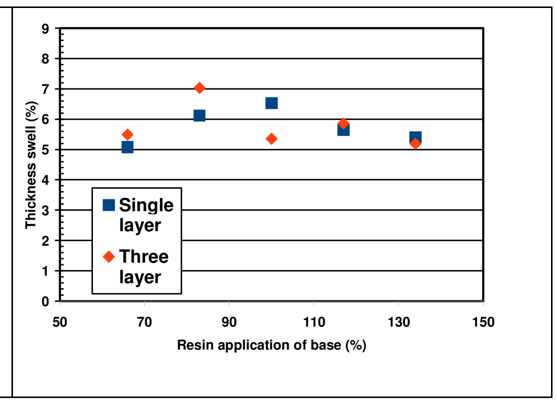
a. PF resin, 1% wax



b. pMDI resin, 1% wax



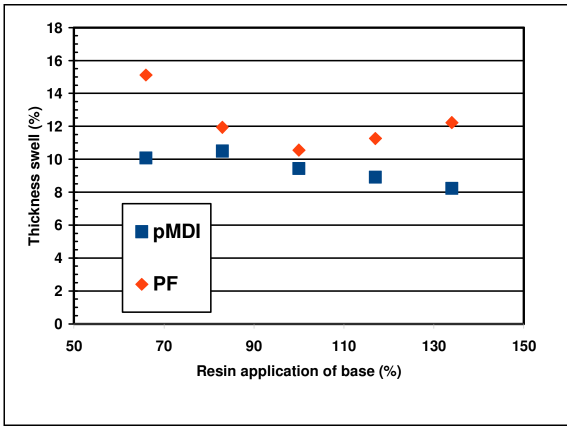
c. PF resin, 0.5% wax



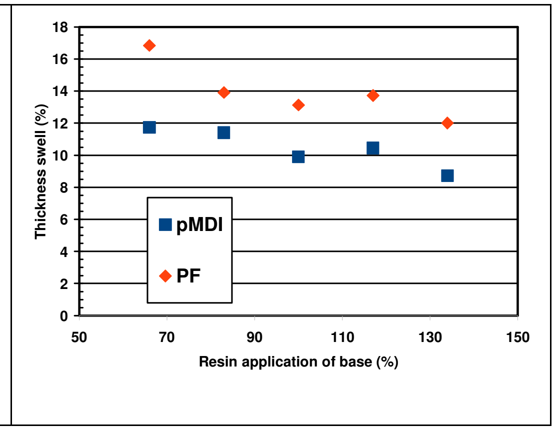
d. pMDI resin, 0.5% wax

Figure 4.3. Effect of board layup on thickness swell of OSB at 80% relative humidity after 196 hours of exposure.

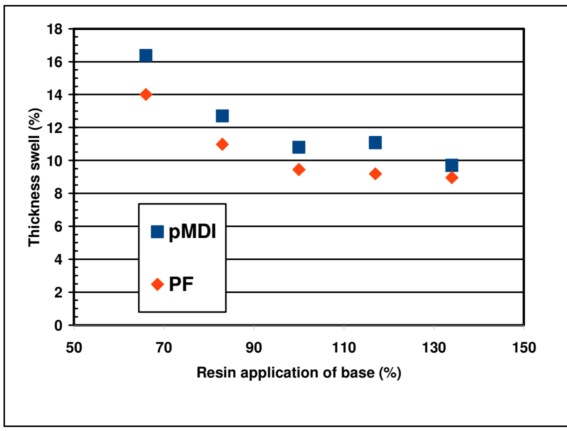
At 90% relative humidity the tendency for thickness swelling to decrease with an increased application rate of resin was more apparent than at 80% (see Fig. 4.4a-4.4c).



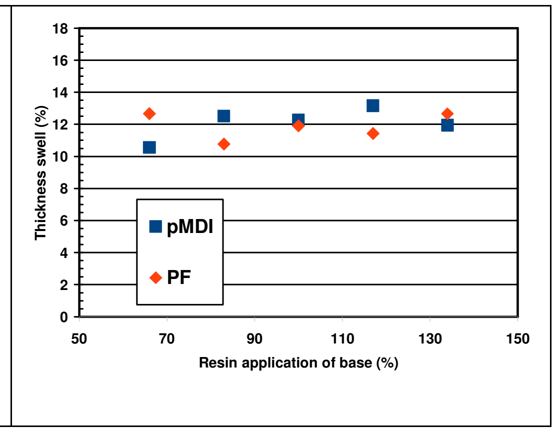
a. Three layer, 1% wax



b. Three layer, 0.5% wax



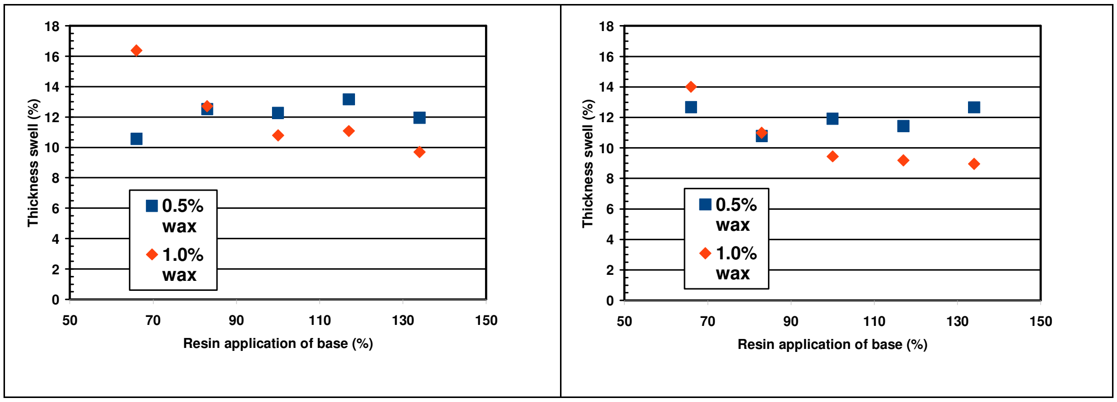
c. Single layer, 1% wax



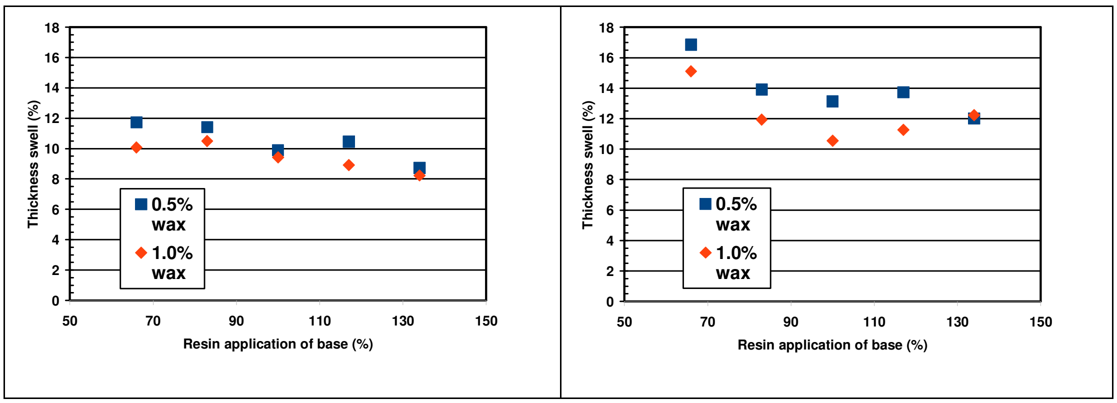
d. Single layer, 0.5% wax

Figure 4.4. Effect of resin type on thickness swell of OSB at 90% relative humidity after 360 hours of exposure.

Layup type seemed to have an effect on which resin performed better. Three layer boards showed pMDI as more resistant, and single layer boards indicated that either PF may perform slightly ahead or that the performance of the two types of resin were roughly similar. A higher wax content for the boards led to either a decrease in thickness swelling or no noticeable effect for the formulation (Fig. 4.5a-4.5d).



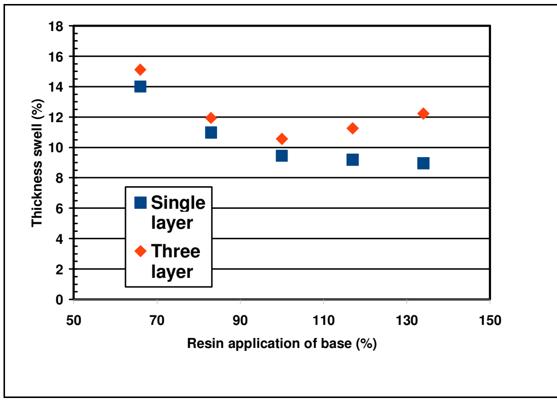
a. Single layer, pMDI resin   b. Single layer, PF resin



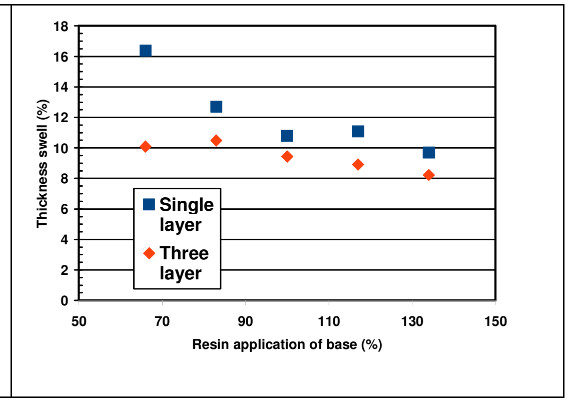
c. Three layer, pMDI resin   d. Three layer, PF resin

Figure 4.5. Effect of wax on thickness swell of OSB at 90% relative humidity after 360 hours of exposure.

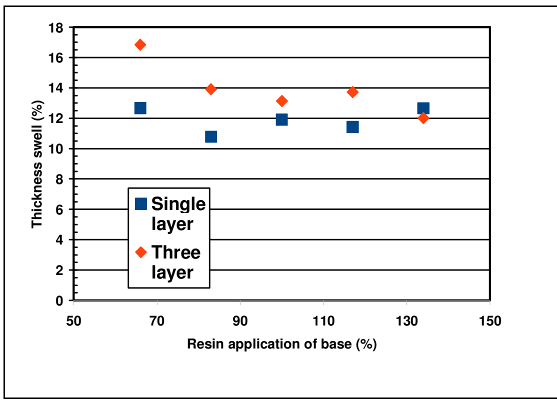
Similar effects could be seen from the graphs comparing board layup type, as only in half of the graphs was there a tendency for single layer to show less TS than three layer (Fig. 4.6a-4.6d).



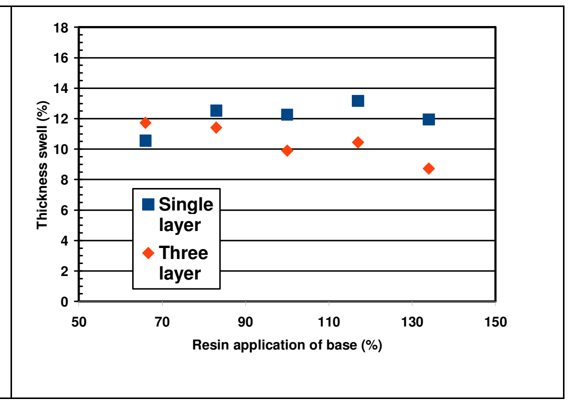
a. PF resin, 1% wax



b. PMDI resin, 1% wax



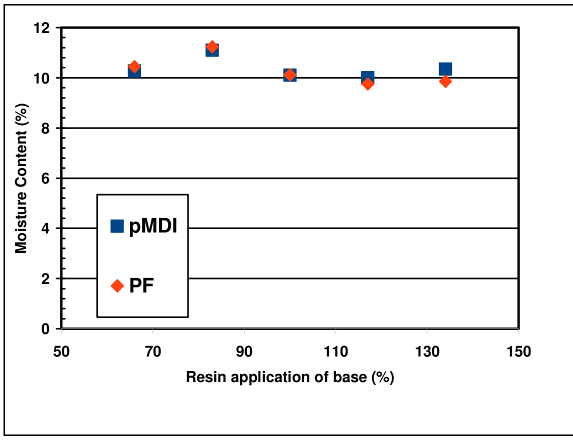
c. PF resin, 0.5% wax



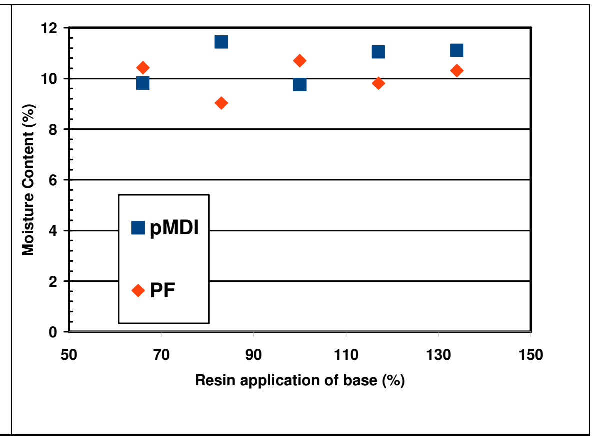
d. PMDI resin, 0.5% wax

Figure 4.6. Effect of board layup on thickness swell of OSB at 90% relative humidity after 360 hours of exposure.

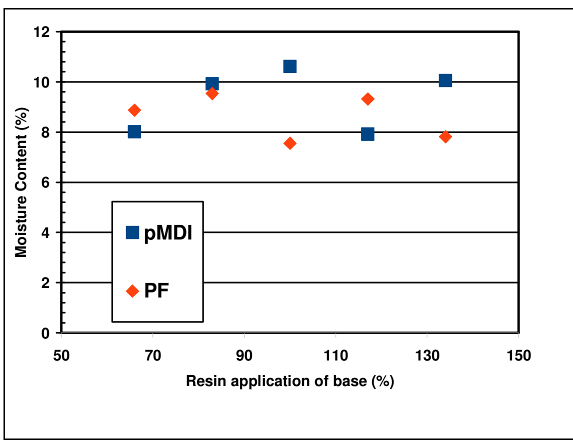
Moisture absorption of samples at 80% relative humidity were largely unaffected by resin type (Fig. 4.7). Minimal variation was observed in Figures 4.7a, b, and d. Both the type of resin and the resin content had little to no effect on the WA. (Fig. 4.7a,-4.7d).



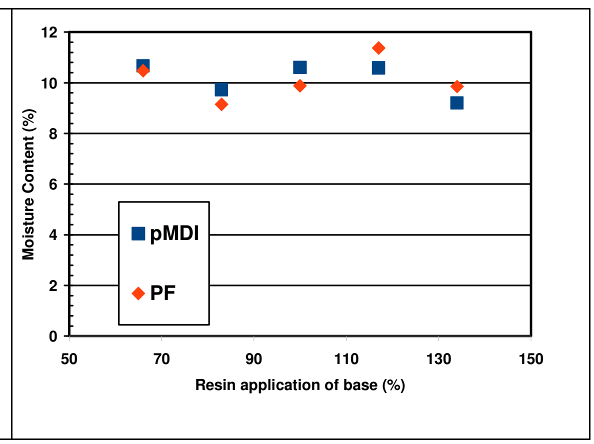
a. Three layer, 1% wax



b. Three layer, 0.5% wax



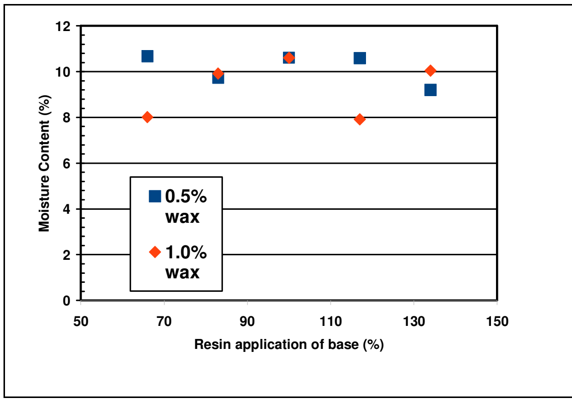
c. Single layer, 1% wax



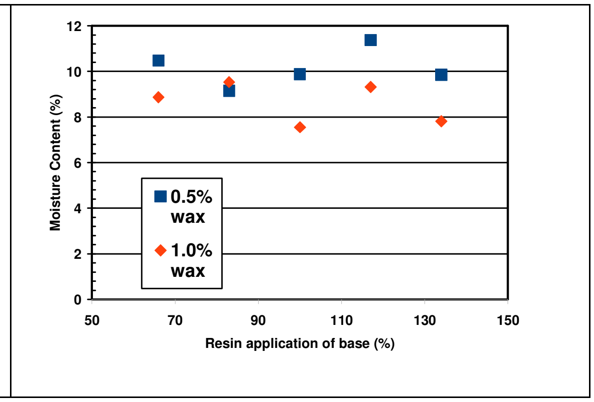
d. Single layer, 0.5% wax

Figure 4.7. Effect of resin type on moisture content of OSB at 80% relative humidity after 196 hours of exposure.

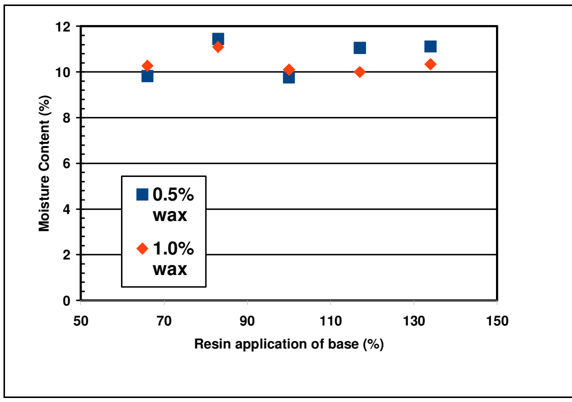
One percent wax was not consistently better than 0.5% wax for reducing water absorption in samples at 80% RH (Fig. 4.8). When comparing wax's effect on moisture content of the samples, there seems to be an average amount of fluctuation in the samples (Fig. 4.8a, 4.8b).



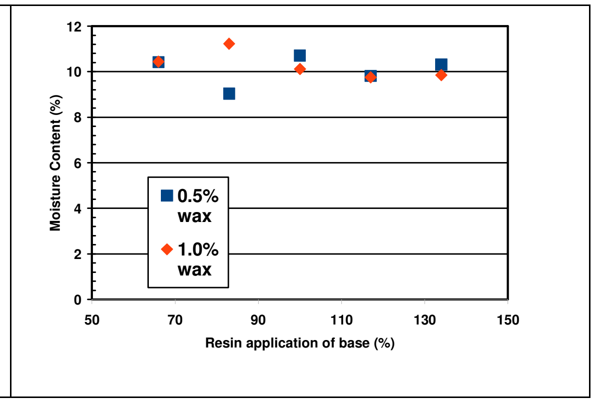
a. Single layer, pMDI resin



b. Single layer, PF resin



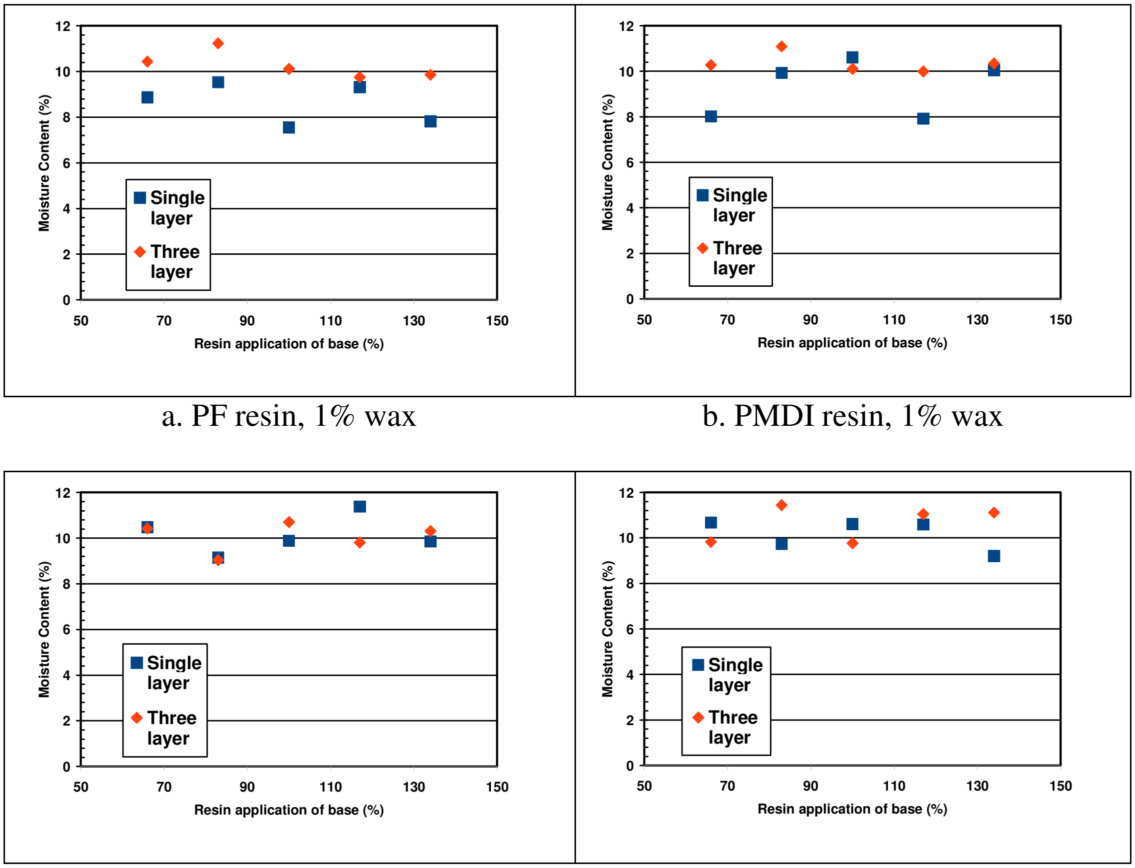
c. Three layer, pMDI resin



d. Three layer, PF resin

Figure 4.8. Effect of wax on moisture content of OSB at 80% relative humidity after 196 hours of exposure.

There were few strong observations between board layup types as they relate to WA in OSB at 80% RH (Fig. 4.9). Single layer tends to be as good or better at preventing moisture absorption. Increasing resin content did not reliably decrease the WA as seen in Figure 4.9.



a. PF resin, 1% wax

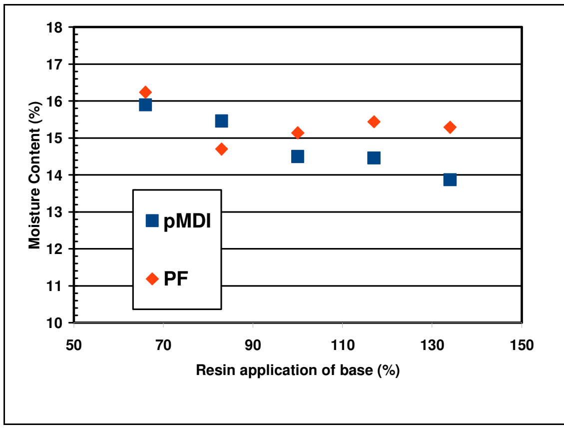
b. PMDI resin, 1% wax

c. PF resin, 0.5% wax

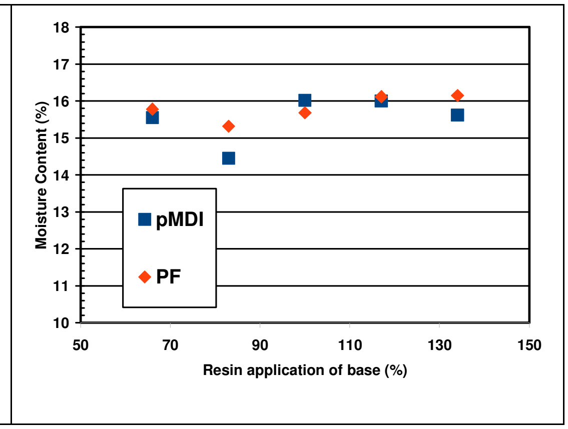
d. PMDI resin, 0.5% wax

Figure 4.9. Effect of board layup on moisture content of OSB at 80% relative humidity after 196 hours of exposure.

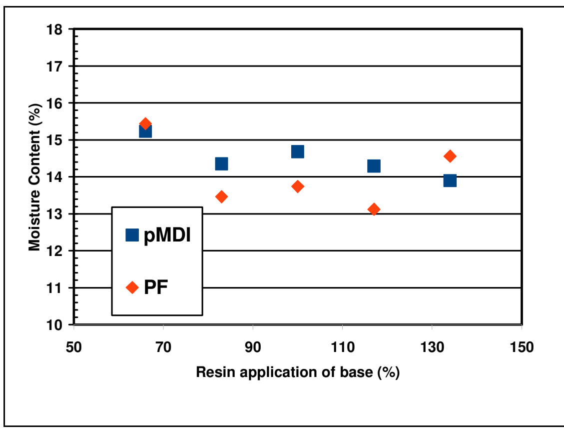
There were cases of increasing resin content decreasing the moisture absorption level (Fig. 4.10a, 4.10c). Raising the level of PF resin caused no change in WA except in Figure 4.10d where it tended to increase the WA.



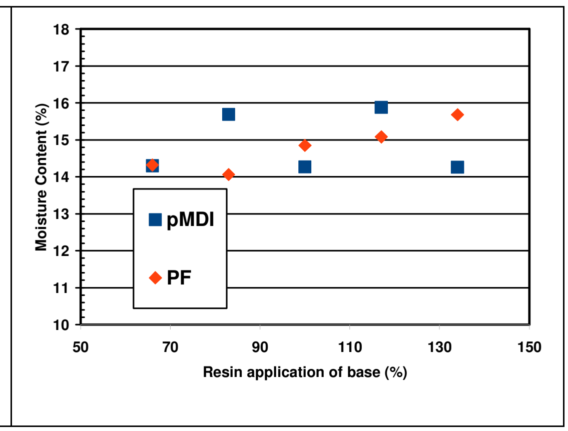
a. Three layer, 1% wax



b. Three layer, 0.5% wax



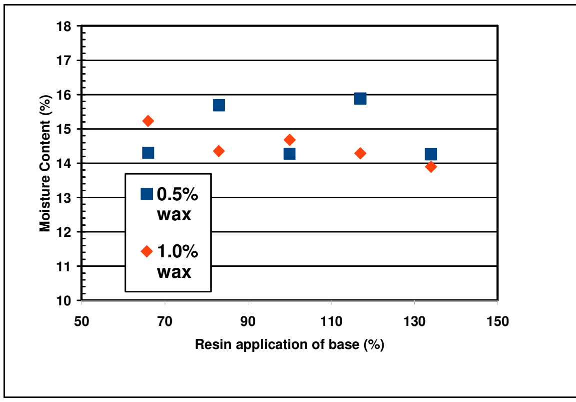
c. Single layer, 1% wax



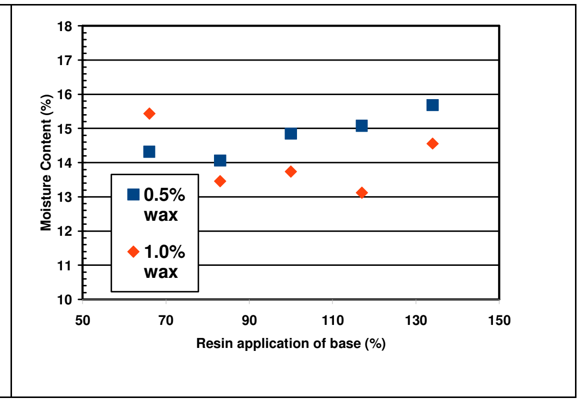
d. Single layer, 0.5% wax

Figure 4.10. Effect of resin type on moisture content of OSB at 90% relative humidity after 360 hours of exposure.

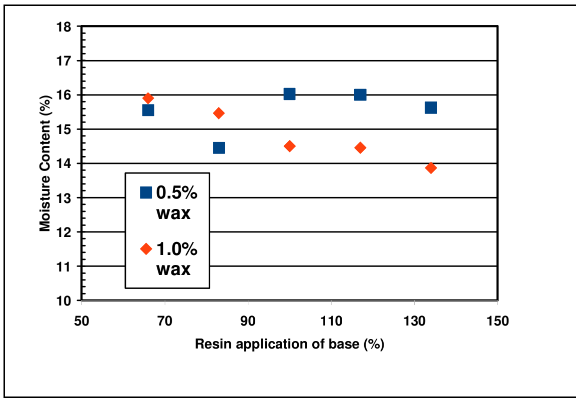
Increasing the percentage of wax reduced the WA of OSB at 90% RH (Fig. 4.11). The most stable graph in the set showed no change in WA based on resin content (Fig 4.11d).



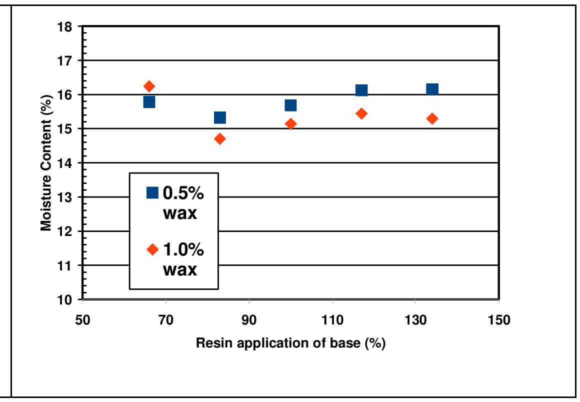
a. Single layer, pMDI resin



b. Single layer, PF resin



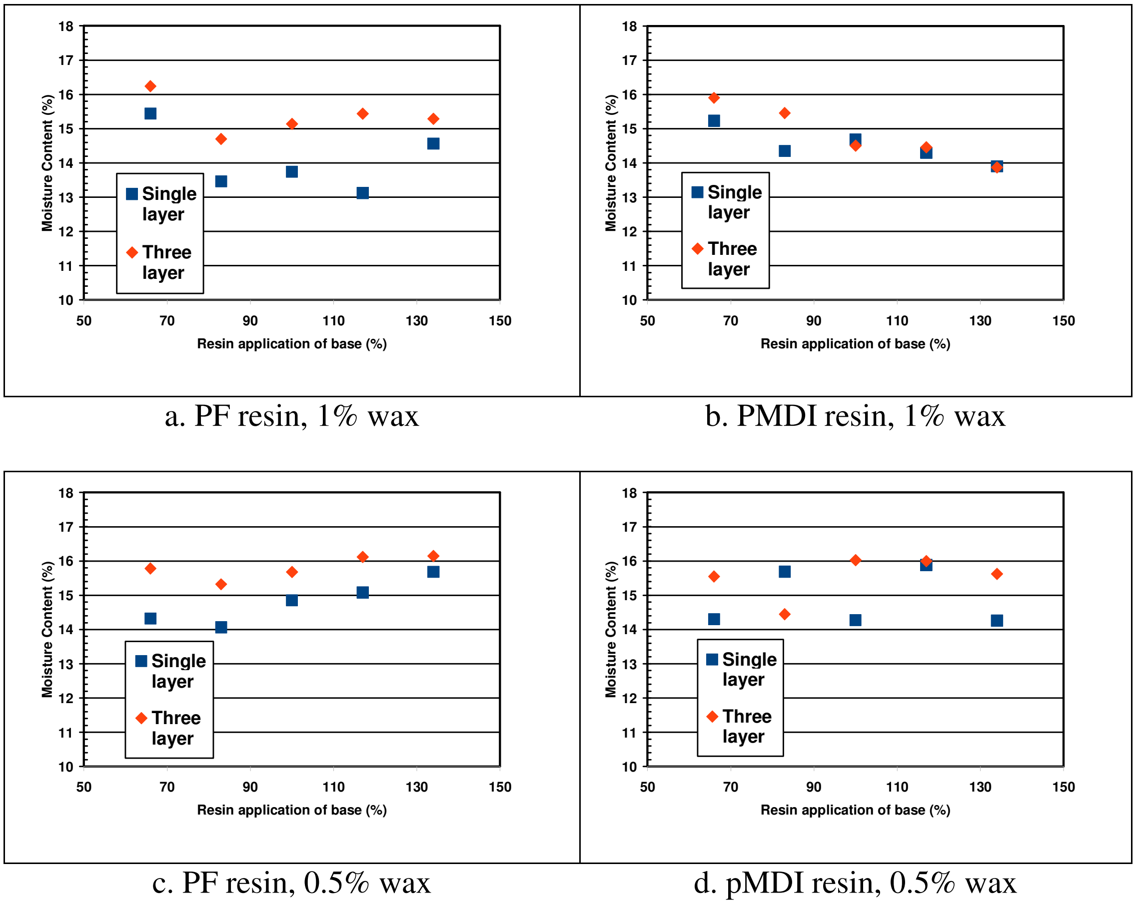
c. Three layer, pMDI resin



d. Three layer, PF resin

Figure 4.11. Effect of wax on moisture content of OSB at 90% relative humidity after 360 hours of exposure.

Also of note was a pattern that indicated that PF resin reduced resistance to moisture when applied at higher applications (Fig. 4.12c). Wax helped to minimize moisture content in two comparisons (Fig. 4.12b, 4.12d), but the others show too much fluctuation to interpret. Board layup seemed to provide significant control on moisture content of OSB, but is subject to further research (Fig. 4.12).



a. PF resin, 1% wax
b. PMDI resin, 1% wax
c. PF resin, 0.5% wax
d. pMDI resin, 0.5% wax

Figure 4.12. Effect of board layup on moisture content of OSB at 90% relative humidity after 360 hours of exposure.

Most of the comparisons of factors were found to be statistically similar. There was also variation present in several graphs of the data. Some of the most noticeable differences in known behaviors of these factors can be explained by the lack of density tracking density for the samples. Density was found to vary by up to twenty percent between some comparisons (Figure 4.3a). For example, the difference in thickness swell between the single layer and three layer groups at 100% resin application rate as seen in Figure 4.3 is most likely due to a significant difference in the average panel density of the samples between the two groups.

Comparison of Mean Values

Table 4.1 allows for easy identification of the various treatment groups in the tables throughout this section.

Table 4.1 Treatment identification codes for tables in Chapter IV.

Board Layup	Resin type	Wax	Resin content (% of base)
T = three layer S = single layer	P = PF M = pMDI	1 = 0.5% 2 = 1.0%	1 = 65% 2 = 83% 3 = 100% 4 = 117% 5 = 134%

Tables were compiled from the output of the SAS software describing the significant differences of the treatment means against WA or TS at either 80% or 90% RH. In Table 4.2, as many as 36 different treatments were statistically similar at an α=0.05. The means for 80% RH were recorded after 196 hours of exposure time, and the means for 90% RH were taken from 360 hours.

Table 4.2 Least square means of all treatments for water absorption at 80% relative humidity.

Treatment ID	Mean (%)	Tukey Grouping[1]				
TM12	11.4	A				
SP14	11.4	A				
TP22	11.2	A				
TM15	11.1	A				
TM22	11.1	A				
TM14	11.0	A				
TP13	10.7	A	B			

Table 4.2 continued

Treatment ID	Mean (%)	Tukey Grouping[1]				
SM11	10.7	A	B	C		
SM13	10.6	A	B	C		
SM23	10.6	A	B	C		
SM14	10.6	A	B	C		
SP11	10.5	A	B	C	D	
TP21	10.4	A	B	C	D	
TP11	10.4	A	B	C	D	
TM25	10.3	A	B	C	D	
TP15	10.3	A	B	C	D	
TM21	10.3	A	B	C	D	E
TP23	10.1	A	B	C	D	E
TM23	10.1	A	B	C	D	E
SM25	10.0	A	B	C	D	E
TM24	10.0	A	B	C	D	E
SM22	9.9	A	B	C	D	E
SP13	9.9	A	B	C	D	E
TP25	9.9	A	B	C	D	E
SP15	9.9	A	B	C	D	E
TM11	9.8	A	B	C	D	E
TP14	9.8	A	B	C	D	E
TM13	9.8	A	B	C	D	E
TP24	9.8	A	B	C	D	E
SM12	9.7	A	B	C	D	E
SP22	9.5	A	B	C	D	E
SP24	9.3	A	B	C	D	E
SM15	9.2	A	B	C	D	E
SP12	9.1	A	B	C	D	E
TP12	9.0	A	B	C	D	E
SP21	8.9	A	B	C	D	E
SM21	8.0		B	C	D	E
SM24	7.9			C	D	E
SP25	7.8				D	E
SP23	7.6					E

[1] means not followed by a common letter differ at p=0.05.

Having a higher average mean WA level than the 80% RH data did not result in more statistically significant treatments at 90% RH (Table 4.3). Again, there were up to 36 statistically similar treatments for WA.

Table 4.3 Least square means of all treatments for water absorption at 90% relative humidity.

Treatment ID	Mean (%)	Tukey Grouping[1]				
TP21	16.2	A				
TP15	16.1	A	B			
TP14	16.1	A	B			
TM13	16.0	A	B	C		
TM14	16.0	A	B	C		
TM21	15.9	A	B	C		
SM14	15.9	A	B	C		
TP11	15.8	A	B	C		
SM12	15.7	A	B	C	D	
TP13	15.7	A	B	C	D	
SP15	15.7	A	B	C	D	
TM15	15.6	A	B	C	D	
TM11	15.5	A	B	C	D	
TM22	15.5	A	B	C	D	
TP24	15.4	A	B	C	D	
SP21	15.4	A	B	C	D	
TP12	15.3	A	B	C	D	E
TP25	15.3	A	B	C	D	E
SM21	15.2	A	B	C	D	E
TP23	15.1	A	B	C	D	E
SP14	15.1	A	B	C	D	E
SP13	14.9	A	B	C	D	E
TP22	14.7	A	B	C	D	E
SM23	14.7	A	B	C	D	E
SP25	14.6	A	B	C	D	E
TM23	14.5	A	B	C	D	E

Table 4.3 continued

Treatment ID	Mean (%)	Tukey Grouping[1]				
TM24	14.5	A	B	C	D	E
TM12	14.4	A	B	C	D	E
SM22	14.3	A	B	C	D	E
SP11	14.3	A	B	C	D	E
SM11	14.3	A	B	C	D	E
SM24	14.3	A	B	C	D	E
SM13	14.3	A	B	C	D	E
SM15	14.3	A	B	C	D	E
SP12	14.1	A	B	C	D	E
SM25	13.9		B	C	D	E
TM25	13.9		B	C	D	E
SP23	13.7			C	D	E
SP22	13.5				D	E
SP24	13.1					E

[1] means not followed by a common letter differ at p=0.05

Despite a wider range of mean values for TS, at 80% RH there were fewer Tukey groupings and only three statistically different treatments (Table 4.4). These treatments, TP11, SP23, and SP25, indicate that increasing the resin content and the wax percentage of OSB produce statistically different, lower mean TS.

Table 4.4 Least square means of all treatments for thickness swelling at 80% relative humidity.

Treatment ID	Mean (%)	Tukey Grouping[1]			
TP11	8.1	A			
TM12	7.0	A	B		
SM23	6.9	A	B		
TP13	6.7	A	B		
SM13	6.5	A	B	C	
TP21	6.5	A	B	C	

Table 4.4 continued.

Treatment ID	Mean (%)	Tukey Grouping[1]			
TP22	6.5	A	B	C	
TP15	6.2	A	B	C	D
SM15	6.1	A	B	C	D
TP23	6.0	A	B	C	D
TM14	5.9	A	B	C	D
SP14	5.7	A	B	C	D
SP22	5.7	A	B	C	D
TM25	5.6	A	B	C	D
SM14	5.6	A	B	C	D
TP25	5.6	A	B	C	D
TP14	5.5	A	B	C	D
TM21	5.5	A	B	C	D
TM11	5.5	A	B	C	D
SM15	5.4	A	B	C	D
TM13	5.4	A	B	C	D
TP24	5.3	A	B	C	D
SM22	5.3	A	B	C	D
SP21	5.2	A	B	C	D
TM15	5.2	A	B	C	D
SP11	5.2	A	B	C	D
TM22	5.2	A	B	C	D
SP15	5.1	A	B	C	D
TM23	5.1	A	B	C	D
SM11	5.1	A	B	C	D
SM21	5.0		B	C	D
TM24	4.9		B	C	D
SP24	4.8		B	C	D
TP12	4.7		B	C	D
SM24	4.6		B	C	D
SP12	4.5		B	C	D
SM25	4.3		B	C	D
SP13	4.3		B	C	D
SP25	3.5			C	D
SP23	3.3				D

[1] means not followed by a common letter differ at p=0.05

In Table 4.5, PF resin was observed to have a higher mean values than pMDI. As well, lower TS means values are associated with higher resin contents across both resin types. The larger mean range led to a greater amount of statistically different treatments. There were as many as 30 similar treatments out of 40 tested at 90% RH.

Table 4.5 Least square means of all treatments for thickness swelling at 90% relative humidity.

Treatment ID	Mean (%)	Tukey Grouping[1]							
TP11	16.8	A							
SM21	16.4	A	B						
TP21	15.1	A	B	C					
SP21	14.0	A	B	C	D				
TP12	13.9	A	B	C	D				
TP14	13.7	A	B	C	D	E			
SM14	13.2	A	B	C	D	E	F		
TP13	13.1	A	B	C	D	E	F		
SM22	12.7	A	B	C	D	E	F	G	
SP11	12.7	A	B	C	D	E	F	G	
SP15	12.7	A	B	C	D	E	F	G	
SM12	12.5	A	B	C	D	E	F	G	H
SM13	12.3	A	B	C	D	E	F	G	H
TP25	12.2	A	B	C	D	E	F	G	H
TP15	12.0			C	D	E	F	G	H
SM15	11.9			C	D	E	F	G	H
TP22	11.9			C	D	E	F	G	H
SP13	11.9			C	D	E	F	G	H
TM11	11.7			C	D	E	F	G	H
SP14	11.4			C	D	E	F	G	H
TM12	11.4			C	D	E	F	G	H
TP24	11.3			C	D	E	F	G	H
SM24	11.1			C	D	E	F	G	H
SP22	11.0			C	D	E	F	G	H

Table 4.5 continued.

Treatment ID	Mean (%)	Tukey Grouping[1]							
SM23	10.8			C	D	E	F	G	H
SP12	10.8			C	D	E	F	G	H
TP23	10.6				D	E	F	G	H
SM11	10.6				D	E	F	G	H
TM22	10.5				D	E	F	G	H
TM14	10.5				D	E	F	G	H
TM21	10.1				D	E	F	G	H
TM13	9.9				D	E	F	G	H
SM25	9.7				D	E	F	G	H
SP23	9.4					E	F	G	H
TM23	9.4					E	F	G	H
SP24	9.2						F	G	H
SP25	9.0						F	G	H
TM24	8.9						F	G	H
TM15	8.7							G	H
TM25	8.2								H

[1] means not followed by a common letter differ at p=0.05.

Equation Modeling Analysis

For all treatments there was a high (>90%) coefficient of determination, implying that equations 3-1 and 3-2 were effective in modeling the behavior of OSB. The equilibrium MA and TS values below are presented as a secondary means to identify the processing variables that had the least amount of MA and TS. MA_∞ was found to vary wildly in some treatments, such as the treatment of three layer board with PF resin at 83% resin content with 0.5% wax at 80% RH (80TP12 in Table 4.6, 4.7). In contrast, the equilibrium thickness swelling of all treatments and repetitions averaged between values of 50 and 60%. The three layer boards presented in table 4.6 and 4.7 were shown to provide the most resistance to water absorption when paired with a pMDI resin.

Table 4.6 Predicted equilibrium water absorption and thickness swelling of three layer boards at 80% relative humidity.

Resin type	Resin %	Wax %	WA_∞	K_{WA}	TS_∞	K_{TS}
PF	65%	0.5%	0.263	0.047	0.577	0.009
PF	65%	1.0%	0.259	0.053	0.527	0.013
PF	83%	0.5%	2.651	0.009	0.577	0.003
PF	83%	1.0%	0.752	0.047	0.527	0.011
PF	100%	0.5%	0.425	0.053	0.545	0.012
PF	100%	1.0%	0.275	0.044	0.523	0.010
PF	117%	0.5%	1.311	0.025	0.551	0.008
PF	117%	1.0%	0.928	0.022	0.525	0.008
PF	135%	0.5%	0.262	0.060	0.513	0.117
PF	135%	1.0%	0.240	0.051	0.519	0.011
pMDI	65%	0.5%	0.543	0.399	0.543	0.012
pMDI	65%	1.0%	0.237	0.058	0.529	0.011
pMDI	83%	0.5%	0.151	0.117	0.545	0.019
pMDI	83%	1.0%	0.129	0.161	0.529	0.017
pMDI	100%	0.5%	0.220	0.052	0.536	0.010
pMDI	100%	1.0%	0.273	0.039	0.522	0.009
pMDI	117%	0.5%	0.139	0.133	0.533	0.015
pMDI	117%	1.0%	0.654	0.033	0.524	0.010
pMDI	135%	0.5%	0.152	0.106	0.529	0.016
pMDI	135%	1.0%	0.187	0.072	0.526	0.014

Table 4.7 Predicted equilibrium water absorption and thickness swelling of three layer boards at 90% relative humidity.

Resin type	Resin %	Wax %	WA_∞	K_{WA}	TS_∞	K_{TS}
PF	65%	0.5%	0.231	0.078	0.629	0.008
PF	65%	1.0%	0.195	0.118	0.569	0.011
PF	83%	0.5%	0.176	0.127	0.579	0.013
PF	83%	1.0%	0.188	0.095	0.558	0.008
PF	100%	0.5%	0.190	0.107	0.570	0.010
PF	100%	1.0%	0.235	0.071	0.543	0.008
PF	117%	0.5%	0.214	0.097	0.586	0.011
PF	117%	1.0%	0.312	0.051	0.541	0.008
PF	135%	0.5%	0.185	0.140	0.542	0.016
PF	135%	1.0%	0.215	0.084	0.544	0.012
pMDI	65%	0.5%	0.188	0.111	0.572	0.011
pMDI	65%	1.0%	0.186	0.126	0.550	0.013
pMDI	83%	0.5%	0.186	0.093	0.570	0.011
pMDI	83%	1.0%	0.217	0.082	0.549	0.010
pMDI	100%	0.5%	0.182	0.396	0.555	0.015
pMDI	100%	1.0%	0.184	0.094	0.541	0.012
pMDI	117%	0.5%	0.181	0.140	0.561	0.016
pMDI	117%	1.0%	0.234	0.068	0.547	0.008
pMDI	135%	0.5%	0.181	0.122	0.544	0.012
pMDI	135%	1.0%	0.193	0.084	0.536	0.010

The single layer boards showed a slight trend to lower WA values with pMDI resin (Table 4.8, 4.9). Overall the single layer boards averaged higher WA levels than the three layer boards. Of note are the treatments of 80% RH single layer, pMDI resin at 83% resin content and 1.0% wax (80SM22) and 80% RH single layer, pMDI resin at 117% resin content and 0.5% wax (80SM14). These single layer treatments have values very similar to those of their three layer counterparts 80TM22 and 80TM14 in Table 4.6.

Table 4.8 Predicted equilibrium water absorption and thickness swelling of single layer boards at 80% relative humidity.

Resin type	Resin %	Wax %	WA_∞	K_{WA}	TS_∞	K_{TS}
PF	65%	0.5%	0.222	0.057	0.539	0.010
PF	83%	0.5%	1.306	0.014	0.545	0.010
PF	100%	0.5%	1.329	0.029	0.557	0.006
PF	117%	0.5%	0.198	0.077	0.552	0.011
PF	135%	0.5%	0.355	0.052	0.549	0.012
PF	65%	1.0%	0.559	0.025	0.553	0.010
PF	83%	1.0%	0.911	0.039	0.568	0.005
PF	100%	1.0%	2.515	0.007	0.746	0.001
PF	117%	1.0%	2.696	0.009	0.537	0.006
PF	135%	1.0%	1.155	0.022	0.538	0.008
pMDI	65%	0.5%	0.133	0.131	0.540	0.017
pMDI	83%	0.5%	0.368	0.040	0.562	0.010
pMDI	100%	0.5%	0.220	0.067	0.564	0.012
pMDI	117%	0.5%	0.130	0.139	0.579	0.016
pMDI	135%	0.5%	2.303	0.011	0.567	0.005
pMDI	65%	1.0%	1.699	0.015	0.575	0.006
pMDI	83%	1.0%	0.133	0.116	0.564	0.013
pMDI	100%	1.0%	0.385	0.035	0.591	0.006
pMDI	117%	1.0%	2.247	0.008	0.539	0.008
pMDI	135%	1.0%	0.856	0.024	0.532	0.007

Table 4.9 Predicted equilibrium water absorption and thickness swelling of single layer boards at 90% relative humidity.

Resin type	Resin %	Wax %	WA_∞	K_{WA}	TS_∞	K_{TS}
PF	65%	0.5%	0.305	0.048	0.580	0.006
PF	83%	0.5%	0.323	0.041	0.575	0.008
PF	100%	0.5%	0.391	0.051	0.587	0.006
PF	117%	0.5%	0.207	0.079	0.566	0.008
PF	135%	0.5%	0.242	0.070	0.587	0.008
PF	65%	1.0%	0.262	0.069	0.604	0.009
PF	83%	1.0%	0.338	0.039	0.583	0.006
PF	100%	1.0%	0.946	0.023	0.562	0.005
PF	117%	1.0%	0.932	0.017	0.559	0.005
PF	135%	1.0%	0.250	0.057	0.551	0.007
pMDI	65%	0.5%	0.477	0.042	0.585	0.006
pMDI	83%	0.5%	0.277	0.070	0.601	0.007
pMDI	100%	0.5%	0.534	0.034	0.607	0.007
pMDI	117%	0.5%	0.254	0.074	0.622	0.008
pMDI	135%	0.5%	0.689	0.034	0.590	0.008
pMDI	65%	1.0%	0.303	0.048	0.630	0.006
pMDI	83%	1.0%	1.221	0.037	0.616	0.005
pMDI	100%	1.0%	0.195	0.096	0.582	0.011
pMDI	117%	1.0%	0.227	0.065	0.568	0.007
pMDI	135%	1.0%	0.514	0.040	0.563	0.006

Table 4.10 and 4.11 demonstrate the behavior of the pMDI resin bonded boards.

Table 4.10 Predicted equilibrium water absorption and thickness swelling of pMDI resin at 80% relative humidity.

Board Layup	Resin %	Wax %	WA_∞	K_{WA}	TS_∞	K_{TS}
Single layer	65%	0.5%	0.133	0.131	0.540	0.017
Single layer	65%	1.0%	1.699	0.015	0.575	0.006
Single layer	83%	0.5%	0.368	0.040	0.562	0.010
Single layer	83%	1.0%	0.133	0.116	0.564	0.013
Single layer	100%	0.5%	0.220	0.067	0.564	0.012
Single layer	100%	1.0%	0.385	0.035	0.591	0.006
Single layer	117%	0.5%	0.130	0.139	0.579	0.016
Single layer	117%	1.0%	2.247	0.008	0.539	0.008
Single layer	135%	0.5%	2.303	0.011	0.567	0.005
Single layer	135%	1.0%	0.856	0.024	0.532	0.007
Three layer	65%	0.5%	0.543	0.399	0.543	0.012
Three layer	65%	1.0%	0.237	0.058	0.529	0.011
Three layer	83%	0.5%	0.151	0.117	0.545	0.019
Three layer	83%	1.0%	0.129	0.161	0.529	0.017
Three layer	100%	0.5%	0.220	0.052	0.536	0.010
Three layer	100%	1.0%	0.273	0.039	0.522	0.009
Three layer	117%	0.5%	0.139	0.133	0.533	0.015
Three layer	117%	1.0%	0.654	0.033	0.524	0.010
Three layer	135%	0.5%	0.152	0.106	0.529	0.016
Three layer	135%	1.0%	0.187	0.072	0.526	0.014

Table 4.11 Predicted equilibrium water absorption and thickness swelling of pMDI resin at 90% relative humidity.

Board Layup	Resin %	Wax %	WA_∞	K_{WA}	TS_∞	K_{TS}
Single layer	65%	0.5%	0.477	0.042	0.585	0.006
Single layer	65%	1.0%	0.303	0.048	0.630	0.006
Single layer	83%	0.5%	0.277	0.070	0.601	0.007
Single layer	83%	1.0%	1.221	0.037	0.616	0.005
Single layer	100%	0.5%	0.534	0.034	0.607	0.007
Single layer	100%	1.0%	0.195	0.096	0.582	0.011
Single layer	117%	0.5%	0.254	0.074	0.622	0.008
Single layer	117%	1.0%	0.227	0.065	0.568	0.007
Single layer	135%	0.5%	0.689	0.034	0.590	0.008
Single layer	135%	1.0%	0.514	0.040	0.563	0.006
Three layer	65%	0.5%	0.188	0.111	0.572	0.011
Three layer	65%	1.0%	0.186	0.126	0.550	0.013
Three layer	83%	0.5%	0.186	0.093	0.570	0.011
Three layer	83%	1.0%	0.217	0.082	0.549	0.010
Three layer	100%	0.5%	0.182	0.396	0.555	0.015
Three layer	100%	1.0%	0.184	0.094	0.541	0.012
Three layer	117%	0.5%	0.181	0.140	0.561	0.016
Three layer	117%	1.0%	0.234	0.068	0.547	0.008
Three layer	135%	0.5%	0.181	0.122	0.544	0.012
Three layer	135%	1.0%	0.193	0.084	0.536	0.010

It can be seen from Table 4.12 and 4.13 that treatments with PF resin had less moisture resistance than formulas with pMDI.

Table 4.12 Predicted equilibrium water absorption and thickness swelling of PF resin at 80% relative humidity.

Board Layup	Resin %	Wax %	WA_∞	K_{WA}	TS_∞	K_{TS}
Single layer	117%	0.5%	0.198	0.077	0.552	0.011
Single layer	65%	0.5%	0.222	0.057	0.539	0.010
Single layer	135%	0.5%	0.355	0.052	0.549	0.012
Single layer	83%	0.5%	1.306	0.014	0.545	0.010
Single layer	100%	0.5%	1.329	0.029	0.557	0.006
Single layer	65%	1.0%	0.559	0.025	0.553	0.010
Single layer	83%	1.0%	0.911	0.039	0.568	0.005
Single layer	135%	1.0%	1.155	0.022	0.538	0.008
Single layer	100%	1.0%	2.515	0.007	0.746	0.001
Single layer	117%	1.0%	2.696	0.009	0.537	0.006
Three layer	135%	0.5%	0.262	0.060	0.513	0.117
Three layer	65%	0.5%	0.263	0.047	0.577	0.009
Three layer	100%	0.5%	0.425	0.053	0.545	0.012
Three layer	117%	0.5%	1.311	0.025	0.551	0.008
Three layer	83%	0.5%	2.651	0.009	0.577	0.003
Three layer	135%	1.0%	0.240	0.051	0.519	0.011
Three layer	65%	1.0%	0.259	0.053	0.527	0.013
Three layer	100%	1.0%	0.275	0.044	0.523	0.010
Three layer	83%	1.0%	0.752	0.047	0.527	0.011
Three layer	117%	1.0%	0.928	0.022	0.525	0.008

Table 4.13 Predicted equilibrium water absorption and thickness swelling of PF resin at 90% relative humidity.

Board Layup	Resin %	Wax %	WA_∞	K_{WA}	TS_∞	K_{TS}
Single layer	65%	0.5%	0.305	0.048	0.580	0.006
Single layer	65%	1.0%	0.262	0.069	0.604	0.009
Single layer	83%	0.5%	0.323	0.041	0.575	0.008
Single layer	83%	1.0%	0.338	0.039	0.583	0.006
Single layer	100%	0.5%	0.391	0.051	0.587	0.006
Single layer	100%	1.0%	0.946	0.023	0.562	0.005
Single layer	117%	0.5%	0.207	0.079	0.566	0.008
Single layer	117%	1.0%	0.932	0.017	0.559	0.005
Single layer	135%	0.5%	0.242	0.070	0.587	0.008
Single layer	135%	1.0%	0.250	0.057	0.551	0.007
Three layer	65%	0.5%	0.231	0.078	0.629	0.008
Three layer	65%	1.0%	0.195	0.118	0.569	0.011
Three layer	83%	0.5%	0.176	0.127	0.579	0.013
Three layer	83%	1.0%	0.188	0.095	0.558	0.008
Three layer	100%	0.5%	0.190	0.107	0.570	0.010
Three layer	100%	1.0%	0.235	0.071	0.543	0.008
Three layer	117%	0.5%	0.214	0.097	0.586	0.011
Three layer	117%	1.0%	0.312	0.051	0.541	0.008
Three layer	135%	0.5%	0.185	0.140	0.542	0.016
Three layer	135%	1.0%	0.215	0.084	0.544	0.012

The equilibrium values for data with 0.5% wax content were in Tables 4.14 and 4.15. There was a relatively even spacing of three layer and single layer boards. Most of the more efficient treatments used pMDI resin.

Table 4.14 Predicted equilibrium water absorption and thickness swelling of 0.5% wax at 80% relative humidity.

Board Layup	Resin type	Resin %	WA_∞	K_{WA}	TS_∞	K_{TS}
Single layer	PF	65%	0.222	0.057	0.539	0.010
Three layer	PF	65%	0.263	0.047	0.577	0.009
Single layer	PF	83%	1.306	0.014	0.545	0.010
Three layer	PF	83%	2.651	0.009	0.577	0.003
Single layer	PF	100%	1.329	0.029	0.557	0.006
Three layer	PF	100%	0.425	0.053	0.545	0.012
Single layer	PF	117%	0.198	0.077	0.552	0.011
Three layer	PF	117%	1.311	0.025	0.551	0.008
Single layer	PF	135%	0.355	0.052	0.549	0.012
Three layer	PF	135%	0.262	0.060	0.513	0.117
Single layer	pMDI	65%	0.133	0.131	0.540	0.017
Three layer	pMDI	65%	0.543	0.399	0.543	0.012
Single layer	pMDI	83%	0.368	0.040	0.562	0.010
Three layer	pMDI	83%	0.151	0.117	0.545	0.019
Single layer	pMDI	100%	0.220	0.067	0.564	0.012
Three layer	pMDI	100%	0.220	0.052	0.536	0.010
Single layer	pMDI	117%	0.130	0.139	0.579	0.016
Three layer	pMDI	117%	0.139	0.133	0.533	0.015
Single layer	pMDI	135%	2.303	0.011	0.567	0.005
Three layer	pMDI	135%	0.152	0.106	0.529	0.016

Table 4.15 Predicted equilibrium water absorption and thickness swelling of 0.5% wax at 90% relative humidity.

Board Layup	Resin type	Resin %	WA_∞	K_{WA}	TS_∞	K_{TS}
Single layer	PF	65%	0.305	0.048	0.580	0.006
Three layer	PF	65%	0.231	0.078	0.629	0.008
Single layer	PF	83%	0.323	0.041	0.575	0.008
Three layer	PF	83%	0.176	0.127	0.579	0.013
Single layer	PF	100%	0.391	0.051	0.587	0.006
Three layer	PF	100%	0.190	0.107	0.570	0.010
Single layer	PF	117%	0.207	0.079	0.566	0.008
Three layer	PF	117%	0.214	0.097	0.586	0.011
Single layer	PF	135%	0.242	0.070	0.587	0.008
Three layer	PF	135%	0.185	0.140	0.542	0.016
Single layer	pMDI	65%	0.477	0.042	0.585	0.006
Three layer	pMDI	65%	0.188	0.111	0.572	0.011
Single layer	pMDI	83%	0.277	0.070	0.601	0.007
Three layer	pMDI	83%	0.186	0.093	0.570	0.011
Single layer	pMDI	100%	0.534	0.034	0.607	0.007
Three layer	pMDI	100%	0.182	0.396	0.555	0.015
Single layer	pMDI	117%	0.254	0.074	0.622	0.008
Three layer	pMDI	117%	0.181	0.140	0.561	0.016
Single layer	pMDI	135%	0.689	0.034	0.590	0.008
Three layer	pMDI	135%	0.181	0.122	0.544	0.012

The treatments with 1.0% wax that had the lowest values of predicted equilibrium water absorption were three layer and single layer boards that were also bonded with pMDI resin (Table 4.16, 4.17).

Table 4.16 Predicted equilibrium water absorption and thickness swelling of 1.0% wax at 80% relative humidity.

Board Layup	Resin type	Resin %	WA_∞	K_{WA}	TS_∞	K_{TS}
Single layer	PF	65%	0.559	0.025	0.553	0.010
Three layer	PF	65%	0.259	0.053	0.527	0.013
Single layer	PF	83%	0.911	0.039	0.568	0.005
Three layer	PF	83%	0.752	0.047	0.527	0.011
Single layer	PF	100%	2.515	0.007	0.746	0.001
Three layer	PF	100%	0.275	0.044	0.523	0.010
Single layer	PF	117%	2.696	0.009	0.537	0.006
Three layer	PF	117%	0.928	0.022	0.525	0.008
Single layer	PF	135%	1.155	0.022	0.538	0.008
Three layer	PF	135%	0.240	0.051	0.519	0.011
Single layer	pMDI	65%	1.699	0.015	0.575	0.006
Three layer	pMDI	65%	0.237	0.058	0.529	0.011
Single layer	pMDI	83%	0.133	0.116	0.564	0.013
Three layer	pMDI	83%	0.129	0.161	0.529	0.017
Single layer	pMDI	100%	0.385	0.035	0.591	0.006
Three layer	pMDI	100%	0.273	0.039	0.522	0.009
Single layer	pMDI	117%	2.247	0.008	0.539	0.008
Three layer	pMDI	117%	0.654	0.033	0.524	0.010
Single layer	pMDI	135%	0.856	0.024	0.532	0.007
Three layer	pMDI	135%	0.187	0.072	0.526	0.014

Table 4.17 Predicted equilibrium water absorption and thickness swelling of 1.0% wax at 90% relative humidity.

Board Layup	Resin type	Resin %	WA_∞	K_{WA}	TS_∞	K_{TS}
Single layer	PF	65%	0.262	0.069	0.604	0.009
Three layer	PF	65%	0.195	0.118	0.569	0.011
Single layer	PF	83%	0.338	0.039	0.583	0.006
Three layer	PF	83%	0.188	0.095	0.558	0.008
Single layer	PF	100%	0.946	0.023	0.562	0.005
Three layer	PF	100%	0.235	0.071	0.543	0.008
Single layer	PF	117%	0.932	0.017	0.559	0.005
Three layer	PF	117%	0.312	0.051	0.541	0.008
Single layer	PF	135%	0.250	0.057	0.551	0.007
Three layer	PF	135%	0.215	0.084	0.544	0.012
Single layer	pMDI	65%	0.303	0.048	0.630	0.006
Three layer	pMDI	65%	0.186	0.126	0.550	0.013
Single layer	pMDI	83%	1.221	0.037	0.616	0.005
Three layer	pMDI	83%	0.217	0.082	0.549	0.010
Single layer	pMDI	100%	0.195	0.096	0.582	0.011
Three layer	pMDI	100%	0.184	0.094	0.541	0.012
Single layer	pMDI	117%	0.227	0.065	0.568	0.007
Three layer	pMDI	117%	0.234	0.068	0.547	0.008
Single layer	pMDI	135%	0.514	0.040	0.563	0.006
Three layer	pMDI	135%	0.193	0.084	0.536	0.010

In addition to solving for equilibrium values for WA and TS, there was also a constant value k determined in both equations. These constants can be used as a measurement of performance for the board treatments. For a constant value WA_∞/TS_∞, increasing k values increase the rate of gain and the total percent WA or TS. K values for all board treatments are presented in Table 4.18. predictions model the averages to within +/-0.2% (Fig. 4.13a-4.13e, Fig. 4.14 c, d). Larger WA or TS seem to cause the predicted values to gain in error (Fig. 4.14a, b). This behavior was recognized by Shi and Gardner (2006b) during development of the equations.

Table 4.18 Comparison of K values obtained from applying Eqs. 3-1 and 3-2.

RH	Board Layup	Resin type	Resin %	Wax %	WA	K_{WA}	R^2 WA	TS	K_{TS}	R^2 TS
80	Single layer	PF	100%	1.0%	2.515	0.007	0.989	0.746	0.001	0.8785
80	Single layer	pMDI	117%	1.0%	2.247	0.008	0.986	0.539	0.008	0.9938
80	Three layer	PF	83%	0.5%	2.651	0.009	0.990	0.577	0.003	0.9642
80	Single layer	PF	117%	1.0%	2.696	0.009	0.992	0.537	0.006	0.9694
80	Single layer	pMDI	135%	0.5%	2.303	0.011	0.986	0.567	0.005	0.9933
80	Single layer	PF	83%	0.5%	1.306	0.014	0.992	0.545	0.010	0.9666
80	Single layer	pMDI	65%	1.0%	1.699	0.015	0.990	0.575	0.006	0.9915
90	Single layer	PF	117%	1.0%	0.932	0.017	0.989	0.559	0.005	0.9839
80	Three layer	PF	117%	1.0%	0.928	0.022	0.994	0.525	0.008	0.9896
80	Single layer	PF	135%	1.0%	1.155	0.022	0.996	0.538	0.008	0.9949
90	Single layer	PF	100%	1.0%	0.946	0.023	0.994	0.562	0.005	0.9946
80	Single layer	pMDI	135%	1.0%	0.856	0.024	0.995	0.532	0.007	0.9943
80	Single layer	PF	65%	1.0%	0.559	0.025	0.995	0.553	0.010	0.9958
80	Three layer	PF	117%	0.5%	1.311	0.025	0.987	0.551	0.008	0.9958
80	Single layer	PF	100%	0.5%	1.329	0.029	0.993	0.557	0.006	0.9885
80	Three layer	pMDI	117%	1.0%	0.654	0.033	0.982	0.524	0.010	0.9946
90	Single layer	pMDI	135%	0.5%	0.689	0.034	0.989	0.590	0.008	0.9920
90	Single layer	pMDI	100%	0.5%	0.534	0.034	0.989	0.607	0.007	0.9965
80	Single layer	pMDI	100%	1.0%	0.385	0.035	0.992	0.591	0.006	0.9880
90	Single layer	pMDI	83%	1.0%	1.221	0.037	0.990	0.616	0.005	0.9870
80	Single layer	PF	83%	1.0%	0.911	0.039	0.994	0.568	0.005	0.9928
90	Single layer	PF	83%	1.0%	0.338	0.039	0.994	0.583	0.006	0.9898
80	Three layer	pMDI	100%	1.0%	0.273	0.039	0.994	0.522	0.009	0.9927
80	Single layer	pMDI	83%	0.5%	0.368	0.040	0.993	0.562	0.010	0.9913
90	Single layer	pMDI	135%	1.0%	0.514	0.040	0.993	0.563	0.006	0.9966
90	Single layer	PF	83%	0.5%	0.323	0.041	0.992	0.575	0.008	0.9828
90	Single layer	pMDI	65%	0.5%	0.477	0.042	0.991	0.585	0.006	0.9979
80	Three layer	PF	100%	1.0%	0.275	0.044	0.987	0.523	0.010	0.9914

Table 4.18 continued.

RH	Board Layup	Resin type	Resin %	Wax %	WA	K_{WA}	R^2 WA	TS	K_{TS}	R^2 TS
80	Three layer	PF	65%	0.5%	0.263	0.047	0.988	0.577	0.009	0.9862
80	Three layer	PF	83%	1.0%	0.752	0.047	0.992	0.527	0.011	0.9974
90	Single layer	PF	65%	0.5%	0.305	0.048	0.993	0.580	0.006	0.9941
90	Single layer	pMDI	65%	1.0%	0.303	0.048	0.992	0.630	0.006	0.9926
80	Three layer	PF	135%	1.0%	0.240	0.051	0.989	0.519	0.011	0.9927
90	Single layer	PF	100%	0.5%	0.391	0.051	0.990	0.587	0.006	0.9943
90	Three layer	PF	117%	1.0%	0.312	0.051	0.987	0.541	0.008	0.9921
80	Three layer	pMDI	100%	0.5%	0.220	0.052	0.995	0.536	0.010	0.9958
80	Single layer	PF	135%	0.5%	0.355	0.052	0.994	0.549	0.012	0.9902
80	Three layer	PF	65%	1.0%	0.259	0.053	0.987	0.527	0.013	0.9917
80	Three layer	PF	100%	0.5%	0.425	0.053	0.991	0.545	0.012	0.9865
90	Single layer	PF	135%	1.0%	0.250	0.057	0.990	0.551	0.007	0.9349
80	Single layer	PF	65%	0.5%	0.222	0.057	0.991	0.539	0.010	0.9861
80	Three layer	pMDI	65%	1.0%	0.237	0.058	0.990	0.529	0.011	0.9942
80	Three layer	PF	135%	0.5%	0.262	0.060	0.990	0.513	0.117	0.9953
90	Single layer	pMDI	117%	1.0%	0.227	0.065	0.992	0.568	0.007	0.9963
80	Single layer	pMDI	100%	0.5%	0.220	0.067	0.991	0.564	0.012	0.9950
90	Three layer	pMDI	117%	1.0%	0.234	0.068	0.991	0.547	0.008	0.9921
90	Single layer	PF	65%	1.0%	0.262	0.069	0.990	0.604	0.009	0.9775
90	Single layer	PF	135%	0.5%	0.242	0.070	0.989	0.587	0.008	0.9977
90	Single layer	pMDI	83%	0.5%	0.277	0.070	0.987	0.601	0.007	0.9924
90	Three layer	PF	100%	1.0%	0.235	0.071	0.988	0.543	0.008	0.9958
80	Three layer	pMDI	135%	1.0%	0.187	0.072	0.988	0.526	0.014	0.9922
90	Single layer	pMDI	117%	0.5%	0.254	0.074	0.988	0.622	0.008	0.9965
80	Single layer	PF	117%	0.5%	0.198	0.077	0.989	0.552	0.011	0.9911
90	Three layer	PF	65%	0.5%	0.231	0.078	0.992	0.629	0.008	0.9926
90	Single layer	PF	117%	0.5%	0.207	0.079	0.992	0.566	0.008	0.9934
90	Three layer	pMDI	83%	1.0%	0.217	0.082	0.986	0.549	0.010	0.9962
90	Three layer	pMDI	135%	1.0%	0.193	0.084	0.991	0.536	0.010	0.9924
90	Three layer	PF	135%	1.0%	0.215	0.084	0.992	0.544	0.012	0.9917
90	Three layer	pMDI	83%	0.5%	0.186	0.093	0.991	0.570	0.011	0.9949
90	Three layer	pMDI	100%	1.0%	0.184	0.094	0.988	0.541	0.012	0.9783

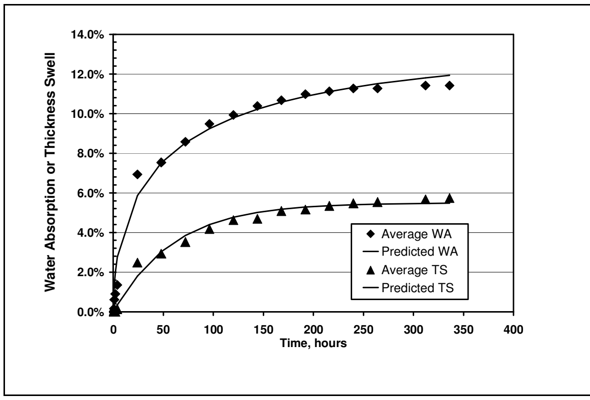
Table 4.18 continued.

RH	Board Layup	Resin type	Resin %	Wax %	WA	K_{WA}	R^2 WA	TS	K_{TS}	R^2 TS
90	Three layer	PF	83%	1.0%	0.188	0.095	0.992	0.558	0.008	0.9962
90	Single layer	pMDI	100%	1.0%	0.195	0.096	0.989	0.582	0.011	0.9926
90	Three layer	PF	117%	0.5%	0.214	0.097	0.990	0.586	0.011	0.9931
80	Three layer	pMDI	135%	0.5%	0.152	0.106	0.992	0.529	0.016	0.9939
90	Three layer	PF	100%	0.5%	0.190	0.107	0.993	0.570	0.010	0.9944
90	Three layer	pMDI	65%	0.5%	0.188	0.111	0.989	0.572	0.011	0.9944
80	Single layer	pMDI	83%	1.0%	0.133	0.116	0.983	0.564	0.013	0.9907
80	Three layer	pMDI	83%	0.5%	0.151	0.117	0.987	0.545	0.019	0.9804
90	Three layer	PF	65%	1.0%	0.195	0.118	0.987	0.569	0.011	0.9967
90	Three layer	pMDI	135%	0.5%	0.181	0.122	0.990	0.544	0.012	0.9969
90	Three layer	pMDI	65%	1.0%	0.186	0.126	0.988	0.550	0.013	0.9939
90	Three layer	PF	83%	0.5%	0.176	0.127	0.988	0.579	0.013	0.9926
80	Single layer	pMDI	65%	0.5%	0.133	0.131	0.981	0.540	0.017	0.9968
80	Three layer	pMDI	117%	0.5%	0.139	0.133	0.988	0.533	0.015	0.9933
80	Single layer	pMDI	117%	0.5%	0.130	0.139	0.977	0.579	0.016	0.9859
90	Three layer	PF	135%	0.5%	0.185	0.140	0.988	0.542	0.016	0.9977
90	Three layer	pMDI	117%	0.5%	0.181	0.140	0.988	0.561	0.016	0.9946
80	Three layer	pMDI	83%	1.0%	0.129	0.161	0.976	0.529	0.017	0.9946
90	Three layer	pMDI	100%	0.5%	0.182	0.396	0.987	0.555	0.015	0.9860
80	Three layer	pMDI	65%	0.5%	0.543	0.399	0.993	0.543	0.012	0.9800

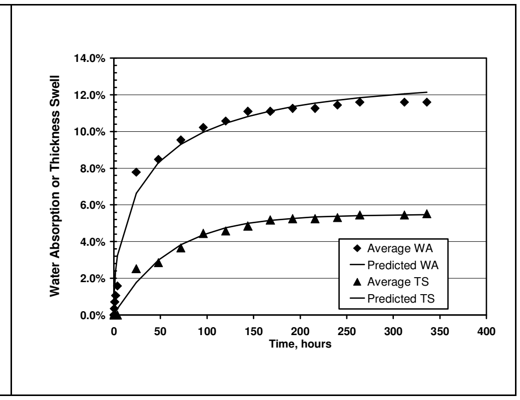
Table 4.18 was ordered according to increasing k values for water absorption. From the table it was seen that a given treatment's k value for WA would be similar in rank to the TS k value; that is to say that large k values for WA would correlate to large k values for TS. Display of the table also revealed that the higher equilibrium water absorption or thickness swelling numbers were linked to the lower k values by their treatment type. By treatment type, single layer boards and higher resin contents were

linked to lower k values. Three layer boards and 0.5% wax were linked with higher k values.

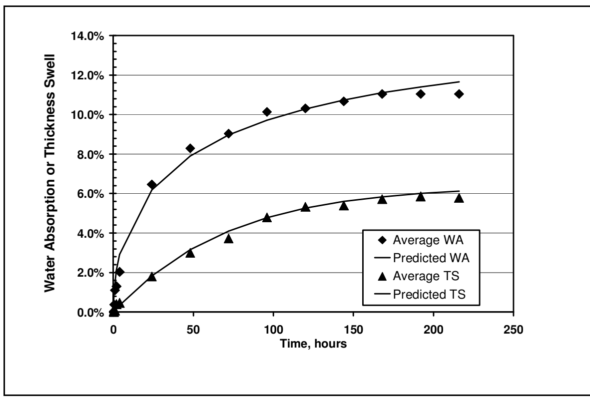
Ten board treatments were picked to determine the prediction accuracy of Eqs. 3-1 and 3-2. The choices of treatments were made based on variables that showed noticeable performance with their WA_{∞}, TS_{∞}, or k values (Fig. 4.13). Predicted WA and TS are tracked against the average WA or TS of the treatment. In most cases the predictions model the averages to within +/-0.2% (Fig. 4.13a-4.13e, Fig. 4.14 c, d). Larger WA or TS seem to cause the predicted values to gain in error (Fig. 4.14a, b). This behavior was recognized by Shi and Gardner (2006b) during development of the equations.



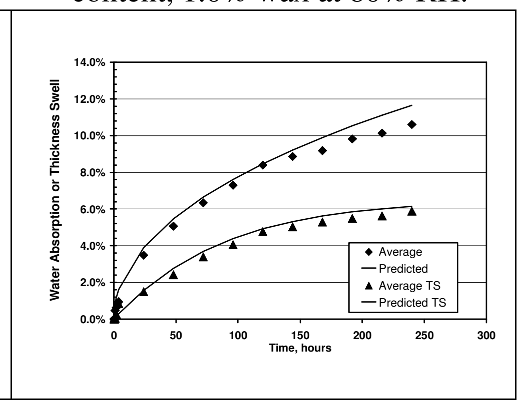
a. Single layer, pMDI, 65% resin content, 0.5% wax at 80% RH.



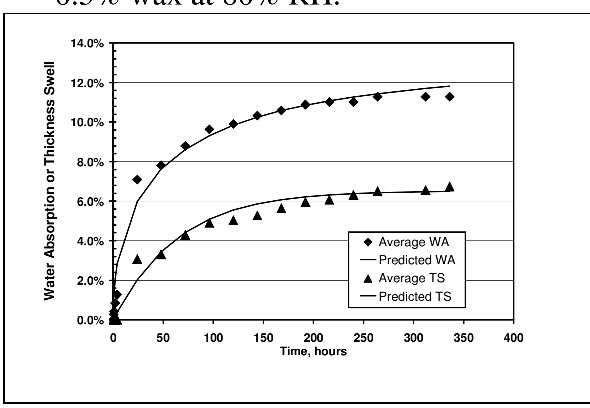
b. Three layer, pMDI, 83% resin content, 1.0% wax at 80% RH.



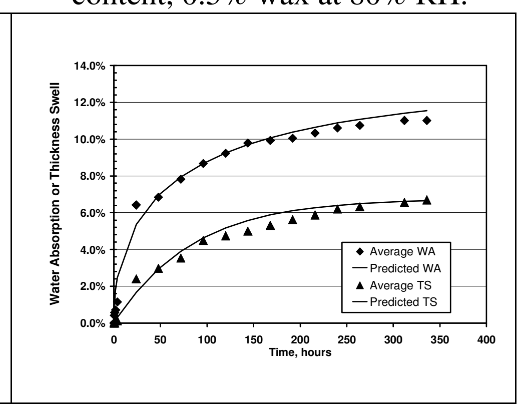
c. Three layer, pMDI, 117% resin content, 0.5% wax at 80% RH.



d. Three layer, pMDI, 65% resin content, 0.5% wax at 80% RH.

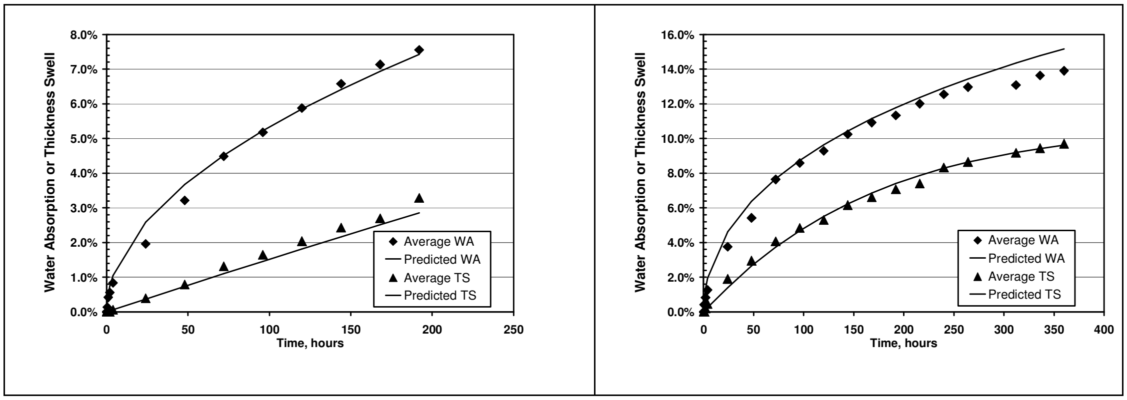


e. Single layer, pMDI, 117% resin content, 0.5% wax at 80% RH.



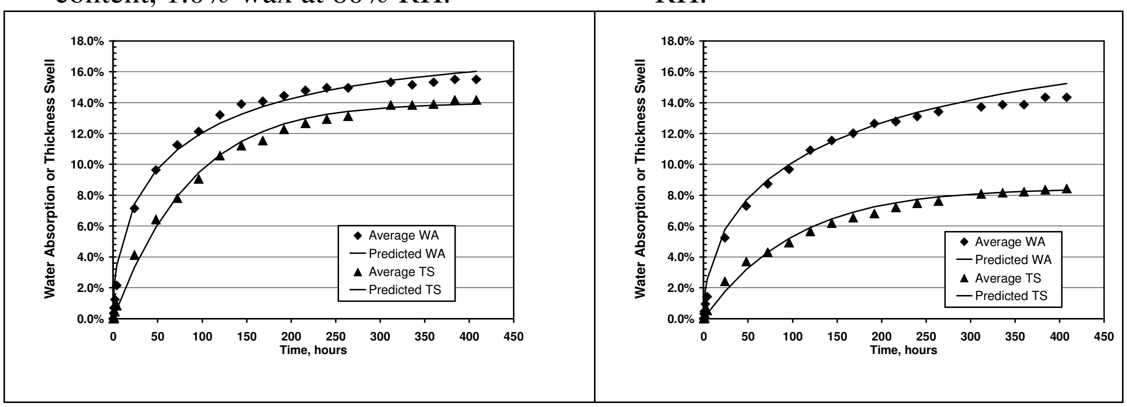
f. Single layer, pMDI, 83% resin content, 1.0% wax at 80% RH.

Figure 4.13 Predicted water absorption and thickness swell models for six different treatments.



a. Single layer, PF resin, 100% resin content, 1.0% wax at 80% RH.

b. Single layer, pMDI resin, 134% resin content, 1.0% wax at 90% RH.



c. Three layer, PF resin, 83% resin content, 0.5% wax at 90% RH.

d. Three layer, pMDI resin, 134% resin content, 1.0% wax at 90% RH.

Figure 4.14. Predicted water absorption and thickness swell models for four different treatments.

CHAPTER V

CONCLUSIONS

Water absorption and thickness swelling behavior of OSB was observed in this study. In particular, the study followed the effects of processing variables for OSB. Variables included board layup, resin type, resin content, and percentage of wax. Samples were measured inside an environmental chamber from oven dry weight to equilibrium at either 80% or 90% relative humidity. Board layup as a processing variable was most effective at minimizing water absorption and thickness swelling of OSB when the strands are arranged in one randomly oriented single layer rather than three cross oriented layers. The improved dimensional stability of single layer panels may be a result of the presence of more void zones in a three layer OSB panel. In most cases the choice between phenol formaldehyde and isocyanate resin showed pMDI was slightly better at decreasing the WA and TS of OSB. There were cases of both decreasing WA and TS with increasing resin content as well as board treatments that were not improved by addition of more resin. Increasing the presence of wax in a board panel was shown to increase the dimensional stability.

Least squared means for WA and TS values showed that almost all board treatments were statistically similar at both 80% and 90% RH. Treatments with single layers and high resin contents were found to have lower mean WA and TS than three layer boards with low resin content.

After investigating the processing variables, the water absorption and thickness swell data was applied to equations developed for wood fiber and wood fiber/polymer composites. Output from the modeling software showed a coefficient of determination greater than 0.9 for all treatments. One of the unknowns solved for by the equations was the equilibrium moisture absorption or thickness swell. The values were sorted in tables in order to gain more understanding of the processing variables. The tables support the findings from the graphs of WA and TS over resin content: single layer boards show tend to have greater dimensional stability as well as an increased resin content and percentage of wax. The second unknown solved by the equations was a constant k value. Increasing k values would increase the WA or TS of a treatment. Lower k values were also found to be related to higher relative equilibrium WA or TS. Ten OSB treatments were picked according to their equilibrium WA, TS or k values to be graphed against their predicted equation values of WA and TS. The graphs show the equations accurately modeling the treatments to within 0.2%. These results indicate that these equations model the WA and TS of OSB best at lower equilibrium moisture levels.

This research is significant because the results have confirmed the findings of other researchers by showing that resin content and wax will improve the dimensional stability of OSB. It is also significant because an equation that was not intended for use with OSB was successful in modeling the WA and TS behavior of the wood composite. There may be other wood composites whose WA and TS can be modeled successfully by these equations.

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