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EFFECT OF RESIN AND WAX RATIO ON OSB PROPERTIES

A Thesis Presented for the

Master of Science Degree

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Trairat Neimsuwan

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ABSTRACT

Oriented Strandboard (OSB) was made for construction purpose. Mat structure especially resin and wax ratio had an influence on major panel properties such as bending strength properties, stiffness properties, internal bonding, water absorption, thickness swell and so on. Thickness swell was an important property of OSB for using in construction and outdoor facilities. The purpose of this study was to investigate the effects of resin and wax ratio on OSB properties and rapidly predict OSB properties using near infrared spectroscopy. The laboratory OSB panels were fabricated as a multiple layer (three layers) mat structure including, orientation, resin types (phenol formaldehyde (PF) and polymeric methylene diphenyl diisocyanate (pMDI)), resin ratio (surface resin content/core resin content), and wax ratio (surface wax content/core wax content). The NIR data were collected from specimen at the wavelength between 350 to 2500 nm. Both principal component analysis (PCA) and partial least square analysis (PLS) were used to analyze the data. Increase of resin ratio can improve MOR and MOE especially in parallel direction including TS of laboratory made OSB. Increase of wax ratio can improve MOR, MOE, IB and TS in OSB with PF as core resin. However, decrease of wax ratio can improve MOR, MOE and IB.

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CHAPTER 1

INTRODUCTION

1.1 Background

Oriented strandboard (OSB) products are widely used in North America as structural materials. The accepted bending strength, stiffness, and dimensional stability of OSB should meet standard requirement (CSA, 1993). OSB is typically manufactured as a multiple layer (three or five layers) for manipulating bending performance. Many parameters affect panel properties such as layer characteristics (three and five layers), resin formula, resin types, resin loading, wax loading, species and species distribution, furnish quality, orientation, and shell ratio (the ratio on a weight basis of face materials to core materials) (Wang et al, 2003). Thickness swell is one of the important properties to enhance dimensional stability because thickness swell highly affects panel strength both within process and after process. The optimization of mat structure, including resin types, resin and wax ratio, is the purpose for this study. Lu and Lam (2001) said thickness swell is time-dependent, moisture-dependent and density-dependent. Traditional thickness swell measurement using caliper measurement of the whole panel thickness cannot explain the whole behavior of thickness swell. Therefore, the optical layer thickness swell was developed to explain the behavior of thickness swell (Wang et al, 2001 and 2003).

1.2 Objectives

The objectives of this study were to investigate the effects of mat structure parameters, especially resin and wax ratio, on the layer thickness swell. For this purpose, the followings were necessary:

1.2.1 To investigate the effect of resin types (PF and MDI), and resin/wax ratio on the properties of laboratory produced OSB sheathing and flooring panels.

1.2.2 To identify face and core thickness swell contributions relative to total thickness swell.

CHAPTER 2

REVIEW OF RELEVANT LITERATURE

2.1 Introduction

The utilization of wood composites has significantly increased all over the world, especially in North America. The increasing use of wood composites results in continuous growth of the wood composites industry. Oriented strandboard (OSB) is used as a construction material. The optimum properties are required for commercial purpose. To reduce the cost of manufacture, the optimization of raw material factors to reach the acceptable board properties was studied worldwide during the last four decades. Dimensional stability, especially thickness swell is an important property for construction applications of wood composites. Parameters affecting thickness swell of OSB include mat structure, furnish characteristics, and pressing condition. Mat structure means strand orientation, moisture content distribution, species and species distribution, and amount of layers. The furnish characteristics include moisture content of strand, resin and wax loading, resin and wax distribution, furnish geometry. The pressing condition includes pressing temperature, opening schedule, press type, and press closing time. All parameters are the key factors for OSB properties including thickness swell (Wang and Winistorfer, 2000c and Wang et al, 2003).

Thickness swell consists of two components: 1) the normal thickness swell of wood by itself called recoverable thickness swell, and 2) the release of residual stress during pressing called non-recoverable thickness swell. The large non-recoverable thickness swell was caused from furnish deterioration and permanent strength loss. Some part of thickness swell resulted from the volume of absorbed water. Actually, the

thickness swell was a more serious problem than panel dimension change because the thickness swell had more effect on mechanical and physical properties. The non-recoverable thickness swell came from significant sorption hysteresis and structural changes during the swell process (Suchsland, 1973). Song and Ellis (1997) divided thickness swell into three different components: 1) natural thickness swell of wood, 2) release of residual stress during hot pressing, and 3) non-uniform board structure such as density variation.

Rowell et al (1986) also mentioned that three different phenomena occurred at the first water soak: 1) reversible swell or recoverable swell that resulted in the cell wall components bonding with water by hydrogen links, 2) irreversible swell or non-recoverable swell that resulted in the relief of residual stress during hot pressing and recovery of fiber crushed during hot pressing, 3) uptake of water due to hydrophilic property of wood. The thickness swell was related to the amount of water absorbed below the fiber saturation point.

This chapter discusses the factors related to board properties in order to understand the influence of the raw material factors and process factors on OSB properties. The first part of this chapter mentioned the source of thickness swell. The second part will discuss the characteristics and the properties of solid wood that affect the OSB properties. The third part will discuss mat structure influences on thickness swell. The fourth part will discuss the thickness swell characteristics and release of compression stress dealing with process parameters. The fifth part will discuss hot pressing.

2.2 Solid Wood

2.2.1 Constituents of the Cell Wall

Wood is a complicated material because it is a composite material on its own. Theoretically, composite materials consist of one or more discontinuous (reinforcement) phases and a continuous phase (matrix). Wood has cellulose or microfibril as reinforcement embedded in an amorphous matrix of hemicellulose, lignin and extractives. The cell wall of wood is a highly hygroscopic element. Therefore, the cell wall is the significant factor related to the mechanical properties of wood. The cell wall of wood has a unique structure that gives wood its strength. The cell wall usually consists of three groups of structural matters: framework, matrix, and encrusting material (Kollmann and Cote, 1968). The framework matter is cellulose mostly in the form of microfibrils that consist of discrete bundles called elementary fibrils. Each elementary fibril contains 50-80 cellulose molecules. The matrix and encrusting substances occur in the paracrystalline region of microfibrils in cellulose as well. The cell wall has five different layers: middle lamella (M), primary wall (P) and secondary wall (S1, S2, S3). Each layer has specific properties.

Cellulose is the major component of the cell wall making up nearly 50% of wood substances by weight. Cellulose is the simplest structure in the cell wall. It is a high-molecular weight-linear polymer of glucose units as shown in Figure 2-1. The number of glucose units is as high as 15,000 depending on the location in the cell wall. The chain that links the microfibrils together creates the amorphous and paracrystalline region (see Figure 2-2). However, the functional hydroxyl groups in the amorphous region tend to absorb water molecules. The hydroxyl groups in crystalline region do not interact with

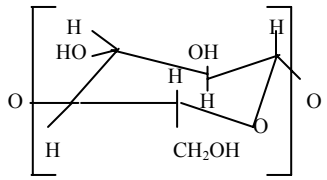

Figure 2-1. Portion of a cellulose molecule (Bodig and Jayne, 1982).

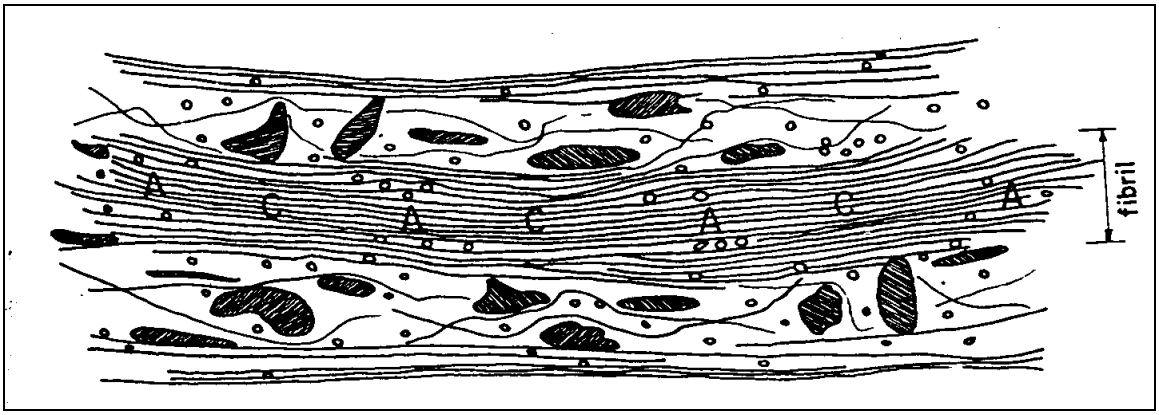

Figure 2-2. Microfibril structures of wood (Bodig and Jayne, 1982).

water molecules except in the amorphous region. Therefore, the amount of amorphous region indicates the dimension change in wood.

Hemicellulose is approximately 30% of the total mass of the cell wall. Hemicellulose is a matrix substance composed of two carbohydrate polymers: xylose and a mannose-containing polysaccharide. Hemicellulose is more related to lignin than cellulose because it has a more amorphous state than cellulose and tends to easily absorb water due to the structure of xylan.

Lignin is a three-dimensional phenylpropanol polymer and is 23% to 33% of wood. In general, lignin is a phenolic polymer and acts like a rubber material. Therefore, lignin tends to afford stiffness to cell wall. Lignin is completely amorphous under normal conditions and the cementing agent that binds individual cells together. Commercially, lignin is usually removed from wood to make high-grade paper. It is easily removed from wood because it is temperature sensitive (Bodig and Jayne, 1982).

2.2.2 Cell Wall Layer

The cell wall is unusually complicated. It has tracheids, fibers, vessels, parenchyma cells, microfibrils, etc. The microfibril is an important part because it adds the strength and is an integral part in cell wall. Generally, all cells are bonded with middle lamella (M). The primary wall is very thin and the secondary wall is thicker. The S2 of the secondary wall is the thickest of all three secondary layers. The important characteristic in the cell wall, especially the secondary wall, is microfibril arrangement. The S2, which is approximately 2 microns, plays an important role in strength consideration of cell wall. The S2 layer has microfibrils oriented almost parallel to fiber axis. Softwood is composed of shorter, less slender parenchyma cells and longer

threadlike tracheids than hardwood. Hardwood has large diameter vessel that act as mechanical support and are used for fluid transportation. They seem the same function as tracheids in softwood. Wood is an orthotropic material whose properties are different in three perpendicular dimensions: longitudinal, radial, tangential (Kollmann and Cote, 1968).

2.2.3 Wood and Water Relationship

Wood as a vascular tissue consists of xylem (wood) and phloem (inner bark). The relation between water and wood is an interesting area for wood technologists. The molecules of water penetrate the cell wall and adhere by hydrogen bonding when moisture contacts the wood. There are two types of water in wood: (1) bound water is the water within the cell wall, (2) free water is the water in the lumen. When moisture contacts the wood surface, the volume usually increases nearly proportional to the volume increase of bound water. The rest of water which is free water in the lumen does not cause further dimension changes. This process is reversible (Kollmann and Cote, 1968). Skaar (1988) said that the strength or mechanical properties of wood generally increases with decreasing moisture content below fiber saturation point, while above that there is essentially no change with loss of moisture.

2.3 Mat Structure

2.3.1 Resin and Wax Considerations

Cohesion is caused by the force of attraction between atoms and molecules. Adhesion is adhesive power of adjacent molecules. In general, the cohesion and adhesion force are identical. There are two kinds of adhesion: mechanical adhesion and specific adhesion. The mechanical adhesion is produced by penetration into open pores on the

surface of wood. Specific adhesion is based on molecular force. The conventional wood composites are made with thermosetting or heat-curing resin to bond lignocellulosic material (fiber) together. Generally, the panel industry uses four synthetic resins: phenol formaldehyde (PF), urea formaldehyde (UF), melamine formaldehyde (MF) and isocyanate compounds. Phenol formaldehyde (PF) is used for the exterior applications requiring exposure durability. In the pressing process, PF resin requires a longer pressing time and higher temperature than other resins. It consequently results in high-energy consumption and low line speeds. The polymeric methylene diphenyl diisocyanate (pMDI) resin is also used in OSB manufacture (Kollmann and Cote, 1968). Scoville (2001) investigated the durability of PF and pMDI adhesives in wood composites. He concluded that pMDI resin resisted accelerated aging cycles better than PF resin. Resin type, content and distribution influenced the panel properties. Marcinko et al (1999) stated that the property development of wood composites bonded with pMDI could be understood by studying the change in molecular motion and the order of wood molecule, which was characterized as material viscoelastic behavior. To develop the bonding strength, the adhesion mechanisms should be deeply understood. Pocius (1997) said the adhesion within lingnocellulosic composites depends on two physicochemical events: 1) the molecular interaction between adherend and adhesive, 2) the viscoelastic behavior of the adhesive and composites. In the molecular and microscopic level, the pMDI changes the physical nature of wood. Kelly (1977) said that increasing resin content in a given particleboard would result in improved inter-particles bonding, which should also improve the thickness stability. However, in all probability there is a level at which additional resin will no longer enhance this bonding and serves only to impregnate or

coat the component particles. Wax, as a sizing agent, is used in all boards in the United States and in boards of many other countries. However, Canada does not require wax for furniture boards. The primary need for wax is to provide the finished products with resistance to aqueous penetration. Another function of wax emulsion in the production of boards is to provide slip characteristics to the wood surfaces. The use of a paraffin wax is widespread in the particleboard industry for both urea formaldehyde and phenol formaldehyde-bonded board. Contradictory claims appear in the literature as to the value of the wax in reducing the dimension changes of particleboard.

2.3.2 Species and Species Distributions

Wang and Winistorfer (2000a) studied the effect of species use and distribution on the vertical density profile formation and panel properties, especially thickness swell of OSB. Pine (*Pinus spp.*), aspen (*Populus spp.*), and hardwood species are used for OSB in commercial manufacture. In general, aspen OSB with a relatively low density and uniform cell structure arrangement is more suitable for manufacturing composite panels and it has better dimensional stability than pine. Most OSB plants use a single species for OSB. However, mixed species are used for research at some factories and universities in order to study and improve the panel properties. They also stated that more than 65 percent of total thickness swell occurred on the high-density surface region. The surface region was the major contributor to total thickness swell of OSB. However, the all-pine panel had total thickness swell greater than the all-aspen panel.

Geimer et al (1997) said the particleboard made from conifer juvenile wood has better bending strength (MOR) and bending stiffness (MOE), including internal bond than boards made from mature wood. When comparing with conifer mature wood, the

conifer juvenile wood has lower water adsorption and thickness swell. Branch woods made particleboard that has better bending strength. However, they have poorer bending stiffness, internal bond properties, water adsorption and thickness swell properties than particleboard made with mature wood. Thickness swell, by definition, is measured in one dimension perpendicular to plane of panel. The reduction of thickness swell is probably caused by water absorption but the major thickness swell resulted from the compressed cell in juvenile wood. Compressed cells can cause springback that was a severe problem in OSB with low specific gravity juvenile wood.

2.4 Thickness Swell

2.4.1 Non-uniform Thickness Swell throughout Panel Thickness

The important parameters affects thickness swell, which was related to mat structure, including mat characteristics (single, three or five layers), orientation, furnish quality, species and species distribution, shell ratio (the ratio on a weight basis of face materials to core materials), resin types, resin formulas, resin ratio (surface resin content/core resin content), wax type, and wax ratio (surface wax content/core wax content). To get better thickness swell properties, the optimization of mat structure was necessary. Optimization of these processing parameters for desirable panel properties is difficult to be accomplished. The thickness swell is a complex phenomenon. One of the most important factors that affects thickness swell is board density. The vertical density profile of particleboard samples closely relates to internal stresses and internal thickness swell. Figure 2-3 shows the vertical density profile of OSB. In general, the low-density layers in the panel swell less than high-density layer (Wang and Winistorfer, 2003). Oriented strandboard (OSB) was hygroscopic and dimensionally unstable when panels

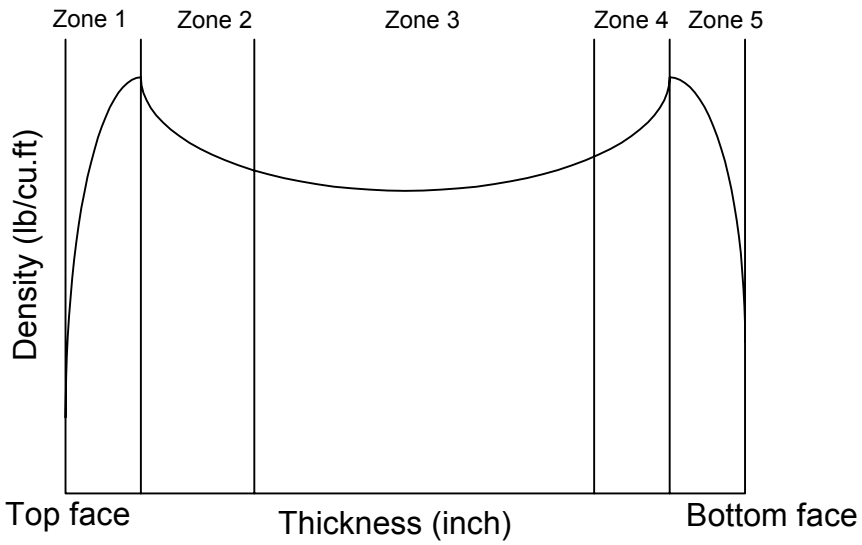

Figure 2-3. The vertical density profile of OSB.

were exposed to a humid environment or immersed in water. The factors effecting thickness swell are wood species, flake geometry, resin types and content, wax type and level, blending efficiency, board density, pressing condition, and special treatment. Flake geometry means flake slenderness ratio (ratio of length to thickness) and flake thickness. The higher slenderness ratio, the higher dimensional stability. The smaller the flake thickness, the smaller the thickness swell. Thickness swell was directly related to the board density and the amount of moisture absorbed. Generally, the thickness swell of the surface region was higher than core region due to the vertical density profile (Lu and Lam, 2001; Halligan, 1970)

In 1991, Liu and McNatt concluded that a high moisture content and high resin content could decrease thickness swell. Mat densification depended on the plastic deformation, the interaction of heat and moisture content, and moisture and heat transfer from center to edges of the mat. When the mat released pressure, thickness swell occurred because of the elasticity of the flake. Also, thickness swell resulted in moisture absorption from the environment of the panel. The total thickness swell related to the resin, environmental conditions, rheological properties of the flake, and density variation. Geimer et al (1998) stated that the thickness swell was proportional to pressure and steam time in the hot press. The reduction of thickness swell occurred from the combination between chemical modification and flake plasticization or lignin flow. The thickness swell usually related to vertical density distribution and panel permeability. The release of internal stress caused thickness swell. Generally, temperature and moisture are closely related to stress relaxation. Therefore, increasing steam pressure can enhance dimensional stability but it reduces mechanical properties at the same time.

2.4.2 Unsteady Contacting Phase on Resin Cure

The vertical density profile formation of wood composites originates from a combination of actions both during consolidation and after the press reaches final position. Wang and Winistorfer (2000d) stated that the condition and properties between the wood component surface and hot platen or among wood component surfaces were not a steady state due to significant density changes throughout the mat even after the press reached final position and maintained at final position. During the entire pressing cycle, resin curing, bond formation, bond breaking, and bond reformation occurred through the mat thickness. This entire phenomenon affected board properties. The bond breaking during resin curing decreased the final bonding strength of the end-product.

2.5 Hot Pressing

2.5.1 Vertical Density Profile

The vertical density profile, vertical density distribution, and the vertical density gradient refer to the density of panel region throughout the panel thickness. The vertical density profile of wood composites has an effect on panel properties particularly on thickness swell. In general, the high-density region has higher internal stress caused by the high thickness swell. Wang and Winistorfer (2000b) stated that the vertical density profile was an unbalanced structure due to variation of raw materials and process parameters. The unbalanced VDP resulted from the preheating of the bottom face of the mat during mat loading into the press. Therefore, the mat density and compaction rate differ between the top and bottom surfaces with the bottom density being larger than the top surface density. By summary, the density increase of the core layer was due to actual wood consolidation and density decrease of the surface layer is due to springback.

Wolcott et al (1999) concluded that initial moisture content also affected VDP distribution. Predicting face and core density profile was feasible. Generally, the larger moisture content migrates from surface to core region in order to soften flake in core area. The higher platen temperature caused the large difference in density between the face and the core. The peak density will move to the core area when there was a high platen temperature. However, increasing pressing closure time resulted in a flatter vertical density distribution.

Figure 2-4 shows the vertical density profile forming during hot pressing. Wang and Winistorfer (2000d) concluded that the vertical density formation is divided into two periods: a consolidation period and an adjusting period. The consolidation period began at mat consolidation and lasted until the hot pressing reached the final position. This period was divided into 2 stages: a uniform consolidation stage and a non-uniform consolidation stage. The uniform consolidation stage starts at the beginning of press closure and ends sometime before the press reaches its final position. During this stage the mat is compressed continually, uniformly and quickly. The consolidation mostly decreases void volume. The vertical density distribution did not occur in this stage. The non-uniform consolidation period begins after initial temperature and moisture changed in the mat surface layer. No evident change occurred in the core region at this stage. The densification of the surface layer increased rapidly. The outer surface layer, especially very close to the surface, did not have the highest compression rate because the mat quickly lost moisture from both outer layers. At the end of this stage, the density profile was highest at the bottom surface and lowest at the core region. The adjusting period started after the press has reached the final position and continued until the end of

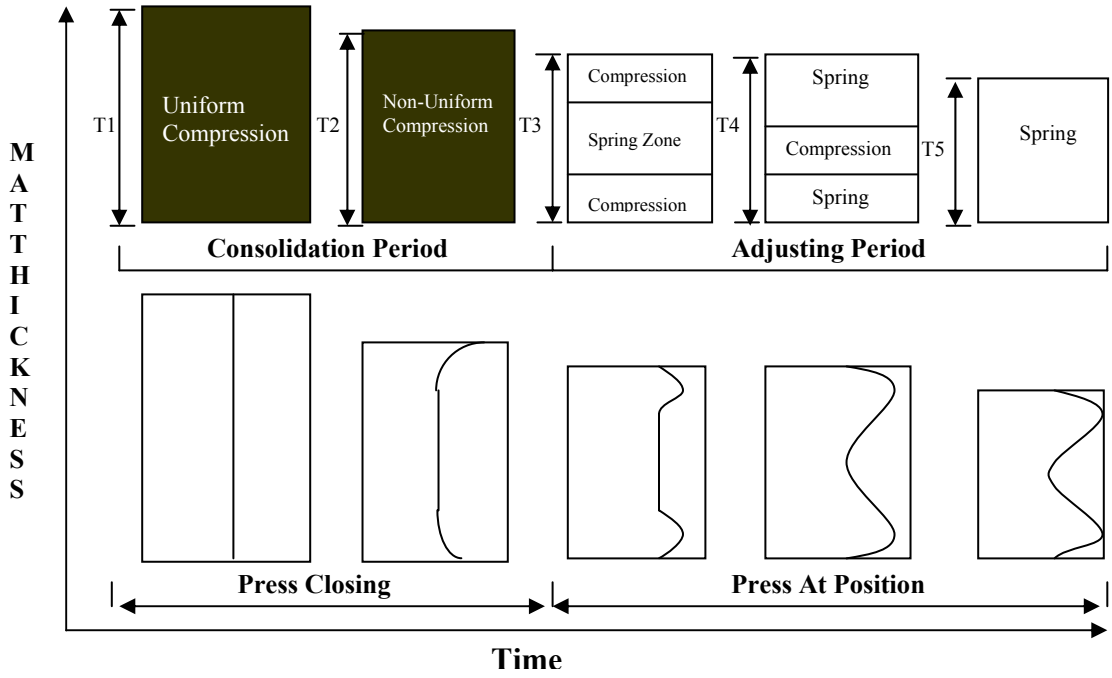

Figure 2-4. Vertical density profiles forming during hot pressing (adapted from Wang and Winistorfer, 2000d).

process. This process was divided into 3 stages: the stage of surface layer consolidation, the stage of core layer consolidation and the stage of springback of the whole panel. During the stage of surface layer consolidation, the temperature gradient played a key role. The flake in the surface region continued to deform in microstructure under maximum pressure. Generally, the surface temperature is higher than the core temperature at the beginning and the press pressure disappears at the surface region due to stress relaxation and flake deformation. Contrary, the cold layer will perform like a spring due to a higher stress-to-strain ratio when the press pressure reaches the maximum. Usually, the center of the mat at the start of pressing has the lowest temperature. Therefore, the core layer mat has the greater spring-like response. The vertical density gradient development mostly occurs in a non-uniform consolidation stage and a stage of surface layer consolidation. If we use a very slow closure rate, the vertical density distribution occurs from the action of a non-uniform consolidation stage. There is a very high compression rate at the mat near the surface and a very high spring rate at the core region. The stage of surface layer consolidation completes when the temperature difference between the surface and core is maximum. In the stage of core layer consolidation, the steam migrates into the core layer and the stress-to-strain ratio of core layer and the density of core layer increase at the low compression rate. Therefore, the core temperature increases and core moisture content is higher than the surface layer. At the same time, the density of the surface layers decrease due to the greater surface layer densification formed under high temperature and compression rate in a non-uniform consolidation stage and a stage of surface layer consolidation. However the high temperature and compression rate cannot be maintained in the stage of core layer

consolidation. In the stage of springback of the whole panel, when the press opens, the steam escapes from the mat at the edge. This event was called springback in which the mat thickness will increase because of internal stress. Usually the mat thickness will be greater than the target thickness due to non-uniform mat structure, moisture, density profiles and internal bonding differences in the mat. Generally, the higher springback will occur at the mat core area.

In 1999, Geimer and Kwon stated that hot pressing was the key process for OSB. The hot pressing process caused complicated phenomenon for OSB, especially internal stress residue inside the mat. They studied the reduction of residual internal stresses and thickness swell by steam injection during hot pressing. They found that the bending strength of OSB in steam injection pressing was significantly lower than conventional pressing. However, the chemical changes during steam injection caused an improvement in dimensional stability. The vertical density profile was closely related to strength properties and thickness swell of OSB. Changes in platen temperature made slight differences in vertical density profile but steam injection made a large reduction in peak density. They also found that the reduction of thickness swell resulted from lignin flow and chemical modification when steam injection was applied to the mat. Thickness swell decreased from 40% for conventional press to 25% for steam injection. The property improvement of OSB using steam injection was dependent on potential plastic flow of lignin and hemicelluloses, and unsteady contacting state between each furnishes. In 2001, Andrews et al said that to reduce thickness swell by controlling the vertical density gradient, a deep understanding of the processing parameter, and raw material factors were required. In oriented strandboard, the hot pressing parameter was most important for

board properties. Particularly press closure rate and furnish moisture content were the two major factors to manipulate vertical density distribution. The furnish MC related to the face zone properties and also pressure closure rate. The higher the moisture content of furnish on the face zone and the faster the press closure rate, the steeper the peak in vertical density profile near surface. Therefore, the press closure rate was a critical factor to control the vertical density profile near the surface. However, the faster press closure rate caused higher flake densification and higher bond development. To increase bonding strength, a faster closure rate and higher furnish moisture in the face zone were used.

2.5.2 Heat and Moisture Movement

The hot pressing is an important process for oriented strandboard (OSB) due to the complex phenomenon that occur during the process. Heat and moisture movement during pressing have been studied by many wood technologists in order to investigate the effect of process parameters on the panel properties. In 1989, Van der Put stated that moisture content had an influence on the wood softening. Generally, increasing moisture can weaken wood strength due to the damage caused by hydrogen bonds in the amorphous part of the cellulose chain. Garcia et al (2001, 2002) stated that during pressing, moisture movement occurred due to gas pressure increases. The internal gas pressure within the mat occurs from the evaporation of bound water in the wood and the reaction of the resin curing. Initially, the water evaporates from both surfaces into the core of the mat and also vapor can move from the center toward the panel edge. Internal gas pressure is a function of the flake alignment, which affects heat transfer, lateral gas flow, horizontal temperature and pressure distribution. The 0% alignment (parallel to hot press dimensions) had much higher pressure than other alignment. Actually, increases in

internal gas pressure can cause moisture vaporization. However, the higher internal gas pressure can destroy the mat structure leading to a deterioration of board properties. In general, the increase in wood densification during pressing had a higher rate of gas pressure than loose particles, which means that the higher the mat density, the higher the internal gas pressure, and the lower the rate of internal gas flow. The moisture migration rate increased when there was a high core moisture content. A higher density mat had lower porosity, lower gas permeability and a lower rate of gas release toward the panel edge. Therefore, the high-density mat has a higher gas pressure. OSB made from flake alignment and random flake structure had a different internal gas pressure and gas permeability. The random flake structure had a lower gas pressure than flake alignment. Therefore, random flake alignment can reduce the gas pressure and gas permeability.

2.5.3 Deformation of Vascular Materials

Wood is a vascular material and is a composite material itself since it consists of vessels as a framework and lignin as a matrix. During compression, the deformation of wood as vascular matter is a function of the cell wall properties (Wolcott, 1989). Lenth and Kamke (1996a and 1996b) stated that the vascular deformation was related to temperature and moisture content. Different moisture content, temperature, and mechanism of cell wall collapse lead to different values of the stress-to-strain ratio. Usually, the form of the cell wall deformation under compression is divided into three categories: brittle, rigid plastic and elastic. The stress-strain curve of vascular material under compression can be divided into three regions: (1) linear elastic, 2) plateau of stress with increasing strain, 3) densification approaching a solid material. Figure 2-5 shows the typical stress-strain curve for cellular materials under compression. The cell wall

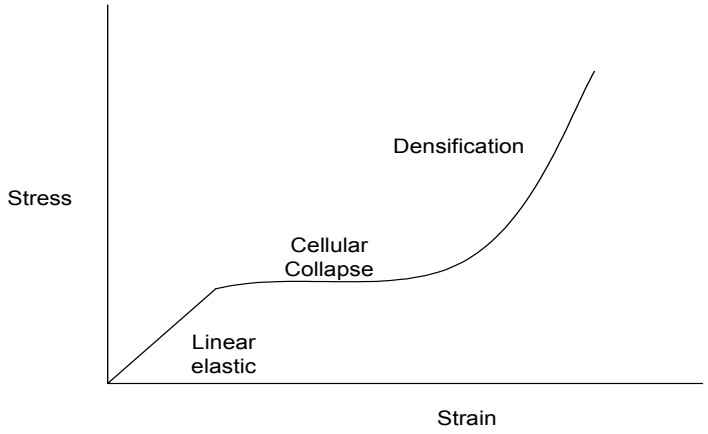

Figure 2-5. Typical stress-strain curves for cellular materials under compression.

deformation could be divided into three stages: (1) initial linear cell wall bending, (2) nonlinear cellular collapse, and (3) final cell wall densification. In initial linear cell wall bending, the materials started to deform in a linear elastic way. There was no vertical density distribution in this stage. The mat was compressed uniformly throughout the thickness with very low compression stress. However, no internal temperature distribution or moisture content gradient occurred. At the end of this stage, the yield point or proportional limit was the point that the vascular cell collapses and material deformation and the stress-strain curve deviated from the linear. The temperature and moisture content profiles developed at a high temperature and high moisture content. If stress was the same, the strain at high temperature was larger than the strain at low temperature. In nonlinear vascular collapse, there was a slight density difference between the surface and the center of panel. Generally the bottom surface had a higher density than the top surface. In final cell wall densification, the stress rapidly increased due to cell wall densification (consolidation). Therefore, the density increase affected the temperature and moisture content distribution. Vascular elastic buckling, plastic formation and cell wall fraction can represent the plateau of stress with increasing strain. The type of cell wall collapse affected the recovery of the cell after the compression force was released (Wolcott et al, 1994). Wang and Lam (1998) stated that the short fiber arrangement influenced the mat properties. They stated that face to core ratio had a significant influence on bending stiffness parallel to face alignment and core structure influence bending stiffness except IB and thickness swell.

2.6 Summary

Many parameters affect thickness swell of OSB such as layer characteristics (single, three and five layers), resin formula, resin types, resin loading, wax loading, species and species distribution, furnish quality, orientation, shell ratio (the ratio on a weight basis of face materials to core materials), orientation, moisture content and distribution, species and species distribution, furnish geometry, pressing temperature, opening schedule, press type and press closure rate. Thickness swell consists of two components: (1) the normal thickness swell of wood called recoverable thickness swell (2) the release of residual stress during pressing called non-recoverable thickness swell (Suchsland, 1973). However, Song and Ellis (1997) divided thickness swell into three different components: 1) natural thickness swell of wood, 2) release of residual stress during hot pressing, 3) non-uniform board structure such as density variation. Higher thickness swell can deteriorate mat structure during hot pressing which is an important process for wood composites. The optimization of mat structure, including resin types, resin ratio and wax ratio, is necessary for OSB.

CHAPTER 3

INFLUENCE OF RESIN AND WAX RATIO ON 7/16" THICK OSB

The objective of this study can be reached with the appropriate design experiment and method. This chapter discusses the raw material, the experimental design, the standard and the machine settings. The chapter is divided into 5 parts: experimental design, materials, panel fabrication and testing procedure, results and discussions, and summary.

3.1 Experimental Design

A 5 x 2 factorial design was used for experiment one (5 resin content combinations and 2 types of resin) and experiment two (5 wax content combinations and 2 types of resin). 7/16" thick panels were made with 3 replications in this study. Face PF resin was used for face layer while core PF and MDI resins were used for core layer. Experiment one studied the resin distribution and experiment two studied the wax distribution.

3.1.1 Experiment One -Resin Influences

This experiment was designed to study the effect of resin ratio on panel properties of 7/16" thick panels. This experiment used two different resin systems for the core layer (PF and MDI). The wax loading was kept constant at 1.7% for the face and core. The total resin loading was kept constant at 4% but the distribution was varied in the face and core layer. The detailed design was listed in Table 3-1.

3.1.2 Experiment Two -Wax Influences

This experiment was designed to study the effect of wax ratio on panel properties of a 7/16" thick panel. This experiment used two different resin systems for core layer

Table 3-1. Experimental design of 7/16" thick OSB for resin influences.

Panel	Resin type		Resin content		
No.	Face	Core	Face	Core	Total
			……%……..		
			1.70% total wax loading		
A-PF-3.0/5.50	PF	PF	3.00	5.50	4.00
B-PF-3.5/4.75	PF	PF	3.50	4.75	4.00
C-PF-4.0/4.00	PF	PF	4.00	4.00	4.00
D-PF-4.5/3.25	PF	PF	4.50	3.25	4.00
E-PF-5.0/2.50	PF	PF	5.00	2.50	4.00
A-MDI-3.0/5.50	PF	MDI	3.00	5.50	4.00
B-MDI-3.5/4.75	PF	MDI	3.50	4.75	4.00
C-MDI-4.0/4.00	PF	MDI	4.00	4.00	4.00
D-MDI-4.5/3.25	PF	MDI	4.50	3.25	4.00
E-MDI-5.0/2.50	PF	MDI	5.00	2.50	4.00

(PF and MDI). The resin loading was kept constant at 4% for the face and core. The total wax loading was kept constant at 1.7% but the distribution was varied in the face and core layer. The detailed design was listed in Table 3-2.

3.2 Materials

The southern yellow pine (*Pinus spp.*) face and core furnish were procured from a J. M. HUBER's factory. The panel was fabricated using Dynea face PF resins (solid content 44.8% and viscosity 27 centipoises) for the face layer and Dynea core PF resin (solid content 45.3% and viscosity 94 centipoises) or MDI resin for the core layer. Wax emulsion (solid content 57.0% and viscosity 82 centipoises) was from Borden Chemical Co. Using industry produced furnish, the OSB panels all had the same shell ratio (face: core = 6:4). Surface layer was composed of face furnish and face PF resin while core layer was composed of core furnish and core PF resin or MDI resin.

3.3 Panel Fabrication

The specimens were made at the Tennessee Forest Products Center's laboratory using southern pine furnish and different resin and wax ratios. The target size was 24 by 24 by 7/16 inches. The target density was 40 lb./cu.ft. The procedure for making the panels was listed below.

3.3.1 Furnish Preparation

Southern pine furnish with moisture content of about 8 - 9% for the face layer and 4-5% for the core layer was procured from an OSB manufacturer. All furnish was screened to remove fines and was contained in bags or barrels to maintain the moisture content.

Table 3-2. Experimental design of 7/16" thick OSB for wax influences.

Panel	Resin type		Wax content		
No.	Face	Core	Face	Core	Total
			……%……..		
			4.00% total resin loading		
F-PF-0.9/2.9	PF	PF	0.9	2.9	1.7
G-PF-1.3/2.3	PF	PF	1.3	2.3	1.7
H-PF-1.7/1.7	PF	PF	1.7	1.7	1.7
I-PF-2.1/1.1	PF	PF	2.1	1.1	1.7
J-PF-2.5/0.5	PF	PF	2.5	0.5	1.7
F-MDI-0.9/2.9	PF	MDI	0.9	2.9	1.7
G-MDI-1.3/2.3	PF	MDI	1.3	2.3	1.7
H-MDI-1.7/1.7	PF	MDI	1.7	1.7	1.7
I-MDI-2.1/1.1	PF	MDI	2.1	1.1	1.7
J-MDI-2.5/0.5	PF	MDI	2.5	0.5	1.7

3.3.2 Mat Forming

A drum blender was used to blend the furnish and resin. Resins were used to fabricate the panel using different formulas for face and core. Wax emulsion was used in this experiment. Forming mats had three layers (two faces and one core). Furnish was oriented at different directions for the face and core using a forming box.

3.3.3 Board Pressing

After blending and forming the panels, the mat (24" x 24" with target thickness 7/16") was pressed at a platen temperature of 204°C with a pressing cycle of 360 seconds and press closure rate of 20 seconds (from initial contact of the mat with the upper platen until final position was reached).

3.4 Testing Procedure

After pressing the panels, the panels were cooled to room temperature for at least two days. Then the panels were cut and properties were tested using CSA and ASTM standards. The procedure for testing specimens was listed below.

3.4.1 Specimen Preparation

- Collected OSB sample boards manufactured at the TFPC's laboratory according to the required specifications from the experimental designs.
- Weighed each panel and measured the three dimensions to obtain the current density value. Thickness was averaged from 4 measurements taken at four edges. Density of each panel was measured before cutting of the board.
- Prepared the testing specimens. According to CSA 0437 Series-93 Standards on OSB and Waferboard, two specimens, 6" x 6", were taken from each panel and prepared for the thickness swell test. Two specimens, 3" x 13", were cut from each panel for the

MOR/MOE test in parallel direction. Two specimens, 3" x 13", were cut from each panel for the MOR/MOE test in perpendicular direction. Ten 2" x 2" specimens across the panel width (24") were cut for the vertical density profile (VDP) test. The top surfaces of each specimen were marked after cutting in order to be able to identify the top surface when testing VDP, bending strength and internal bond. After testing VDP, these specimens were used for the IB test. Six specimens were tested for internal bond (choose 6 from 10 in case some tests failed due to a failure between the specimen and metal block instead of a failure within the specimens). The cutting diagram for the testing specimens from 3 replications of a 20" x 20" panel was shown in Figure 3-1.

- The MOR/MOE test was performed in accordance with CSA 0437 Series-93 Standards on OSB and Waferboard 5.4.1.
- The IB test was performed in accordance with CSA 0437 Series-93 Standards on OSB and Waferboard 5.2.1.
- The density profile test was performed by the x-ray densitometer (QMS Density Profile System). Based on the vertical density profile obtained, face and core layer thickness of each specimen can be determined for later analysis of face/core contribution to the total TS.
- The thickness swell test included two techniques: the ASTM standard technique (ASTM, 2001) for measuring total thickness swell, water absorption and edge thickness swell, and the nondestructive optical technique for determine thickness swell (at two time steps— 24 hours and 96 hours) after submersion in water.

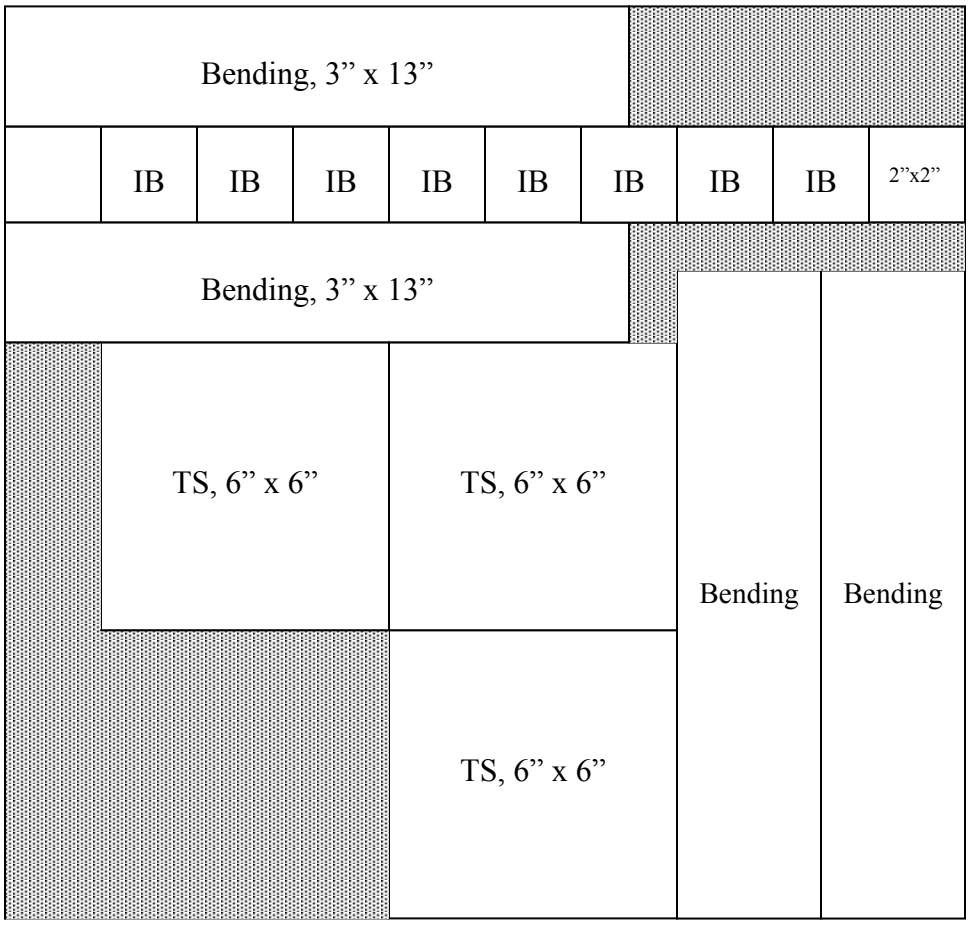

Figure 3-1. The cutting diagram for 7/16” thick OSB.

3.4.2 Bending Strength Test

According to CSA 0437 Series-93 Standards on OSB and Waferboard 5.4.1, two specimens with long dimensions parallel to the long dimension of the panel and two specimens with long dimension perpendicular to the long dimension of the panel were tested. Static bending properties were tested with center loading while the bending specimen was centered in the span. The load was placed continuously at the midspan with a uniform motion of the movable head of the testing machine to the top (compression) side of specimen. The speed of the movable head was calculated using the following formula:

Speed (mm/min) = 0.48 t Equation 1.

Where:

t = the nominal thickness of the board (mm.)

The machine speed should not vary more than 50% from that specified for a given thickness. The support should not cause appreciable crushing of the specimen. To avoid crushing the specimen, the supports were knife-edges, provided with rollers and bearing plates under the specimen at these points. The specimen was loaded at the center of span with the load applied to specimen at a uniform rate.

Calculation of modulus of rupture for each specimen was calculated by the following equation:

$$R = \frac{3PL}{2bd^2}$$ Equation 2.

Calculation of the stiffness (apparent modulus of elasticity) for each specimen was determined by using the following formula:

$$E = \frac{PL^3}{4bd^3y}$$ Equation 3.

Where:

b = width of specimen, in. (mm.)

d = thickness (depth) of specimen, in. (mm.)

E = stiffness (apparent modulus of elasticity), psi (MPa)

L = length of span, in. (mm.)

P = maximum load, lbf (N)

R = modulus of rupture, psi (MPa)

y = center deflection at proportional limit load, in. (mm.)

3.4.3 Internal Bonding Test

According to CSA 0437 Series-93 Standards on OSB and Waferboard 5.2.1, six specimens per panel were tested. Each face of the test specimens was bonded with loading blocks (2" x 2") of steel. The strength of the glue line should be significantly stronger than the strength of each material being tested. The location of the failure was noted (top, core, and bottom). If any test specimens failed due to a failure of the glue line that held the specimen to the metal, then the results of that specimen were discarded and replaced with a specimen coming from the same panel. The test specimen was 2 in. (50 mm.) square with a thickness the same as the finished board. The loading block of steel (2 x 2 x 1 in.) was bonded with a melted resin. The head of the testing machine loaded the specimen until failure occurred. The load was applied continuously throughout the test at a uniform rate of 0.08 in. /in. (cm. /cm.) of thickness per minute.

Calculation of internal bond was determined by using the following formula:

$$IB = \frac{P_{max}}{BL}$$ Equation 4.

Where:

IB = the internal bond strength, psi (MPa)

P_{max} = the ultimate failing load, lbf (N)

B = the width of specimen, in. (mm.)

L = the length of specimen, in. (mm.)

3.4.4 Vertical Density Profile Test

Ten samples from IB specimens were chosen to measure the vertical density profile using the commercial x-ray densitometer (QMS Density Profile System). The x-ray densitometer diagram was shown in Figure 3-2. The average density profile was calculated from ten samples from each panel. The QDP-01X Density Profile measures the attenuation of a collimated x-ray beam that is passed through a sample. The sample density at each measurement point is calculated from the measured attenuation. The QDP-01X used the distance the x-ray penetrated the sample material to calculate the density value from the measured radiation attenuatation. Samples were put into the cassette in the QDP-01X Density Profile. When the cassette was placed in the QDP-01X, the sample was scanned. Automatic caliper and automatic scale were used to measure specimen size and weight.

3.4.5 Thickness Swell Test

After the specimens (6 x 6 in.) were cut from the OSB panels, each edge was slightly sanded using a stationary belt sander. Sander dust was blown out of the sample edge using a pressurized air stream. The midpoint of each edge was marked with

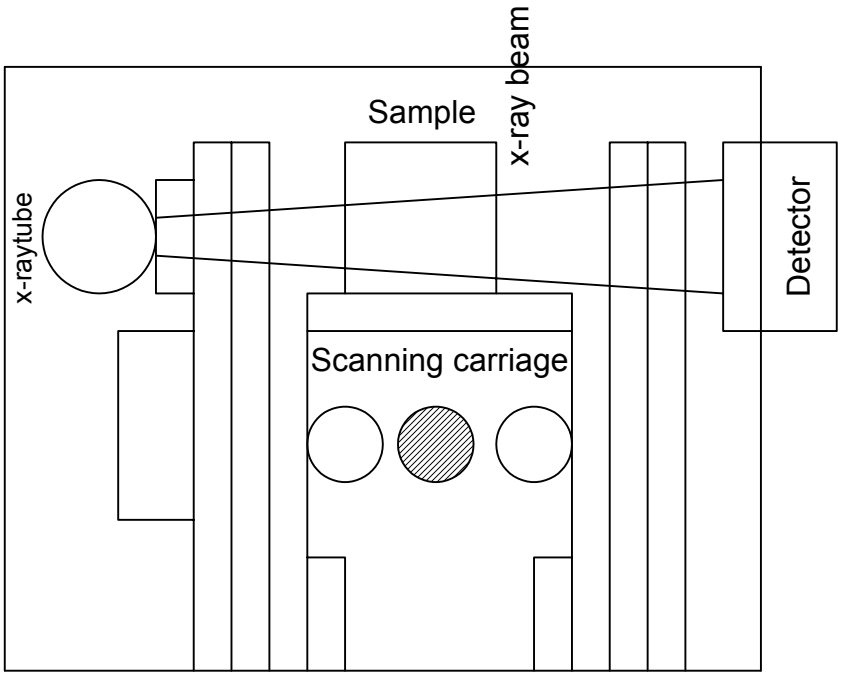

Figure 3-2. Cross-section of QDP-01X showing relationship of sample, x-ray beam, x-ray tube and x-ray detector.

waterproof paint on all four sides to measure the thickness. A special cutter-head was designed and developed in the Tennessee Forest Products Center's laboratory (Wang and Winistorfer 2002). The cutter-head consists of 16 saw blades and 16 shim stocks, which are alternately placed on the mandrel and secured with a locking nut. The sample edges were cut by this machine to make layer strips on the sample edges. The small cut was called slot. The slot was the cut made into the specimen edge. The space between the slots, in which no material was removed, was referred to as the bar. All four edges were cut using cutter head at the mid points. Layer thickness swell, water absorption, total thickness swell (TS) and total edge thickness swell (Edge TS) were measured on each specimen after water exposure times of 24 and 96 hours.

3.4.5.1 Total Thickness Swell

The total thickness swell was measured at the midpoint of each side 1" from the edge using a dial caliper according to the ASTM 1037-92A procedure. Specimens, after initial measurements, were submerged horizontally under 25 mm. of clear water maintained at a temperature of 20°C for specified time intervals (24 hours, 96 hours). Excess surface water was removed before the measurements.

3.4.5.2 Total Edge Thickness Swell

The total edge thickness swell was measured on the edge at the same marked mid-point on each side at the specified time intervals (24 and 96 hours).

3.4.5.3 Water Absorption

Water absorption was based on the weight change of specimens at each water submersion time interval (24 and 96 hours).

3.4.5.4 Layer Thickness Swell

The nondestructive optical technique (Wang et al. 2001) was used to determine TS of 13 discrete layers for 7/16" thick OSB boards. The U.S. patent No. 6,396,590 (Process and system for determination of layer thickness swell of wood composites) issued on May 28, 2002 was used in this study (Wang and Winistorfer, 2002).

The calculation of thickness swell was determined using the following formula;

$$TS = \frac{T_s - T_0}{T_0} x100 \qquad \text{Equation 5.}$$

Where

TS = Thickness swell (%)

T_0 =Thickness before soaked (mm.)

T_s = Thickness after soaking for 24 or 96 hours (mm.)

3.5 Results and Discussions

The relationship between resin types, resin content and wax content in the face and core layers and the properties of OSB such as modulus of rupture, modulus of elasticity, internal bond, thickness swell and water absorption were discussed in this chapter. Particularly, layer thickness swell was an important part of this chapter.

3.5.1 Panel Density and Vertical Density Profile

Figures 3-3 and 3-4 displayed the vertical density profile of 7/16" thick OSB with varied resin and wax ratios. The VDP was divided into three zones; top face, core, bottom face (30%, 40%, 30%). These were divided by zone materials on weight basis. 30%, 40% and 30% of materials on weight basis is in top face, core and bottom face, respectively. The target average density was 40 lb./cu.ft. The average density of the OSB with MDI as

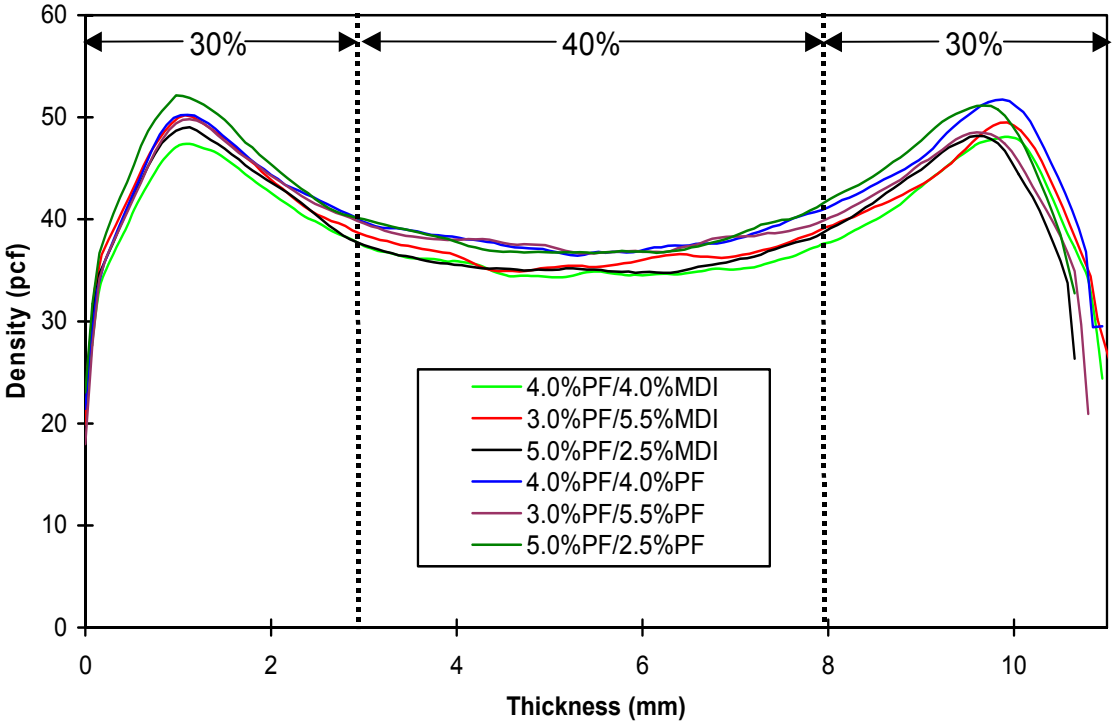

Figure 3-3. The VDP of 7/16" thick OSB with varied resin ratios.

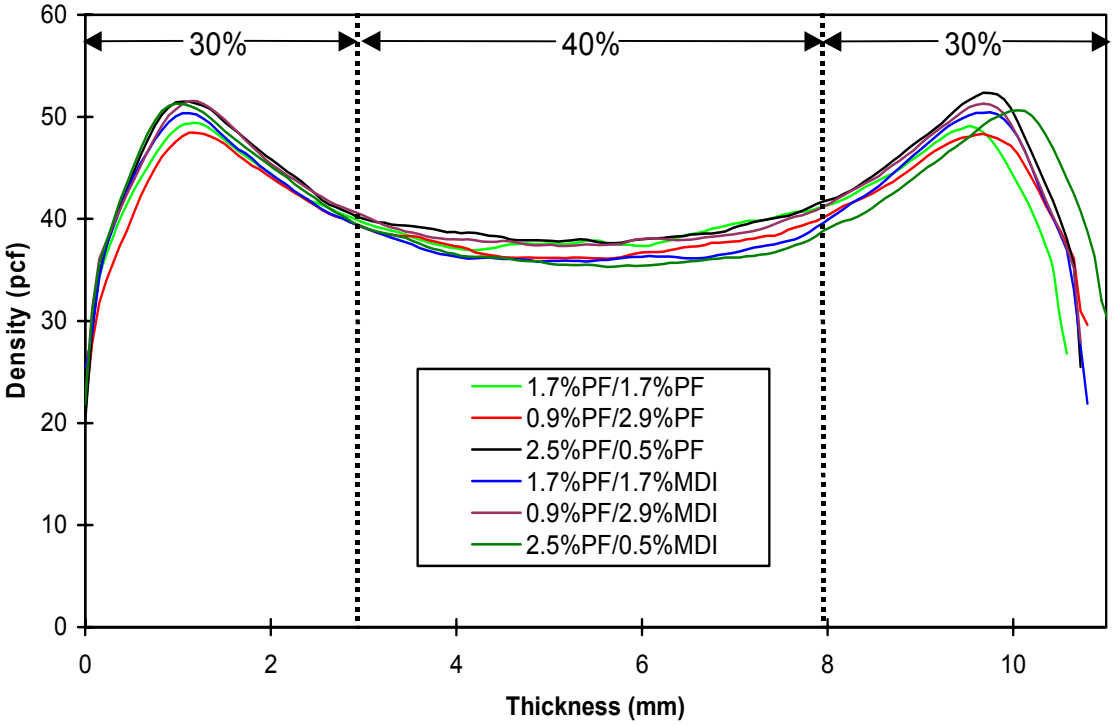

Figure 3-4. The VDP of 7/16" thick OSB with varied wax ratios.

core resin was 39.4 lb./cu.ft while the average density of the OSB with PF as core resin was 40.3 lb./cu.ft. The average density of the OSB with MDI as core resin was lower than the OSB with PF as core resin because MDI as higher solid content which had lower moisture content cannot easily soften furnish under hot pressing. All conditions of the OSB showed a nice and steep density profile (two density peaks very close to the surfaces and wide flat core density region). Higher rate of heat transfer due to higher moisture content caused steep VDP. Theoretically, the heat can migrate faster in the high liquid content region. Different resin content which had different moisture content caused slightly different shape of VDP. Wang et al (2003) stated that the steep VDP (high face density relative to the lower core density) and the narrow density peaks of the surface layers near the surface and high average core density should have the good mechanical properties. The high resin content either in surface or core layer leads to higher moisture content in the mat. Therefore, the mat can be pressed easily. From this phenomenon, the internal stress of mat can be reduced during hot pressing. However, due to the same hot pressing schedule, the shape of VDP was identical.

3.5.2 Mechanical Properties (MOR & MOE and IB)

3.5.2.1 Resin Influences

Figure 3-5 showed the comparison of mechanical properties of 7/16" thick OSB between resin types. The average MOR, MOE and IB of all panels were 21.6, 3637 and 0.370 MPa for the OSB with PF as core resin and 22.7, 3662 and 0.431 MPa for the OSB with MDI as core resin. Comparing panel mechanical properties of the OSB with MDI as core resin with PF as core resin, the OSB with MDI as core resin had noticeably higher average MOR, MOE and IB than the OSB with PF as core resin about 5.1, 0.7 and

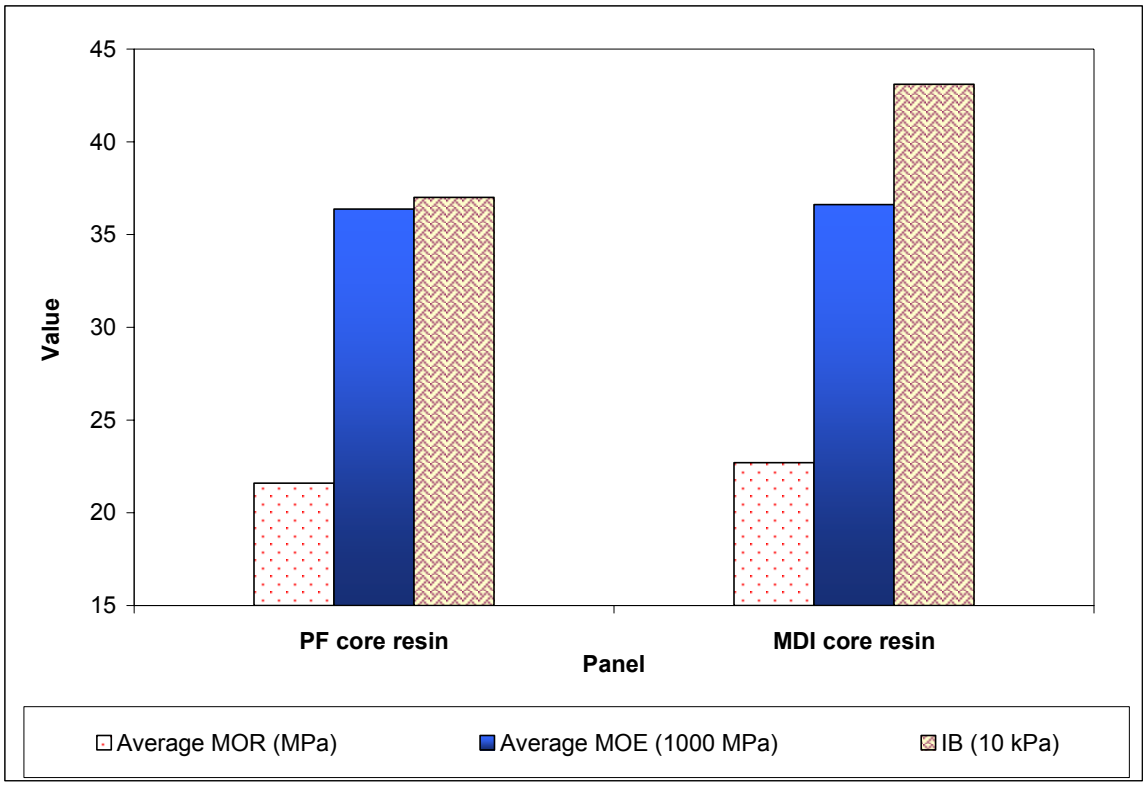

Figure 3-5. Comparison of the mechanical properties of 7/16" thick OSB between resin types.

16.5%, respectively. This seemed to agree with earlier findings (Wilson, 1980 and Galbraith, 1986). Table 3-3 showed the physical and mechanical properties of 7/16" thick OSB with varied resin ratios (the ratio of face resin content to core resin content). Two different resin types were used in this study.

For PF/PF resin, the high resin ratio caused the high MOR and MOE in parallel direction. However, in perpendicular direction, there was no evidence to show the effect of resin ratio. The highest MOR and MOE in the parallel direction were 33.0 MPa and 6229 MPa respectively in panel E-PF-5.0/2.50. This value was higher than CSA standards (29.0, 5500 MPa). The highest average MOR and MOE of the parallel and perpendicular directions were 23.6 and 3969 MPa in panel E-PF-5.0/2.50, which is higher than CSA standards (20.7, 3500 MPa).The IB of panel B-PF-3.5/4.75, C-PF-4.0/4.00 and D-PF-4.5/3.25 were 0.406, 0.398 and 0.367 MPa. The optimization of resin content in surface and core layer had better IB. The orientation had more effect on MOR than MOE because the ratio of parallel to perpendicular direction of MOR was higher than MOE. The OSB with the highest resin ratio had average MOR, MOE and IB higher than the OSB with the lowest resin ratio about 14.5, 8.7 and 0.9%, respectively.

For PF/MDI resin, the high MOR and MOE in both parallel and perpendicular directions were caused by the high resin ratio. The highest MOR, MOE in parallel and perpendicular direction were 34.9, 6581, 16.5 and 1876 MPa respectively in panel E-MDI-5.0/2.50. The highest average MOR and MOE in the parallel and perpendicular directions were 25.7 and 4228 MPa in panel E-MDI-5.0/2.50. The highest IB was 0.484 MPa in panel D-MDI-4.5/3.25. The IB of all panels was higher than CSA 0437 Standard. The OSB with the highest resin ratio had average MOR, MOE higher than the OSB with

Table 3-3. The physical and mechanical properties of 7/16" thick OSB with varied resin ratios.

Panel No.	Density	Thickness	MOR(MPa)			MOE(MPa)			IB(MPa)
	(lb/cu.ft.)	(in.)	parallel(std)	Perpendicular(std)	Par/Per	Parallel(std)	Perpendicular(std)	Par/Per	Value(std)
				PF core resin					
A-PF-(3.0/5.50)	40.5	0.435	26.6 (7.2)	14.8 (2.2)	0.6	5677 (844)	1622 (268)	0.3	0.318 (0.072)
B-PF-(3.5/4.75)	40.5	0.429	26.0 (4.8)	15.5 (3.5)	0.6	5359 (614)	1793 (129)	0.3	0.406 (0.112)
C-PF-(4.0/4.00)	40.8	0.441	28.6 (6.8)	15.3 (4.1)	0.5	5761 (709)	1757 (377)	0.3	0.398 (0.092)
D-PF-(4.5/3.25)	39.7	0.443	24.6 (6.2)	13.1 (2.4)	0.5	5085 (866)	1597 (177)	0.3	0.367 (0.066)
E-PF-(5.0/2.50)	40.2	0.433	33.0 (5.7)	14.3 (2.9)	0.4	6229 (915)	1708 (319)	0.3	0.321 (0.057)
				MDI core resin					
A-MDI-(3.0/5.50)	38.1	0.441	30.1 (7.2)	13.5 (4.6)	0.4	5596 (910)	1381 (270)	0.2	0.377 (0.111)
B-MDI-(3.5/4.75)	39.4	0.433	31.2 (9.3)	14.4 (5.5)	0.5	5486 (1165)	1560 (382)	0.3	0.403 (0.125)
C-MDI-(4.0/4.00)	39.1	0.439	27.5 (8.4)	16.5 (5.2)	0.6	5028 (684)	1750 (355)	0.3	0.417 (0.129)
D-MDI-(4.5/3.25)	39.0	0.434	28.5 (4.5)	16.0 (3.4)	0.6	5362 (740)	1699 (268)	0.3	0.484 (0.117)
E-MDI-(5.0/2.50)	40.2	0.432	34.9 (7.0)	16.5 (3.4)	0.5	6581 (1338)	1876 (327)	0.3	0.432 (0.095)
CSA Standard	-	-	29.0 (-)	12.4 (-)	-	5500 (-)	1500 (-)	-	0.345 (-)

the lowest resin ratio about 17.9, 21.2 and 14.6%. However IB was more sensitive to the effect of resin procure, resin distribution, flake geometry and forming variations. Resin content increases usually improve mechanical and physical properties of OSB panels. Wu (1998) found that the resin content only had a significant effect on MOR in parallel direction. Wang and Lam (1998) stated that face-to-core ratio and core structure strongly influences MOE in parallel direction and did not influence IB and TS. In this study, constant overall resin content was used but resin distribution was varied between the face and core regions. From the results, the high resin ratio caused the high MOR and MOE. The limited number of specimens prevents statistical analysis. A larger number of specimens should be used for composite materials, especially OSB.

3.5.2.2 Wax Influences

Table 3-4 showed the physical and mechanical properties of 7/16" thick OSB with varied wax ratios. For PF/PF resin, the highest MOR and MOE in the parallel and perpendicular directions were 28.9, 17.5, 6022 and 1734 MPa in panel J-PF-2.5/0.5. The highest average MOR and MOE in the parallel and perpendicular directions were 23.2 and 3879 MPa in panel J-PF-2.5/0.5. Comparing the highest wax ratio with the lowest wax ratio, the highest wax ratio caused the high MOR and MOE in both parallel and perpendicular directions. The highest IB was 0.440 MPa in panel J-PF-2.5/0.5, which is above the 0.345 MPa requirement based on the CSA 0437 Standard. The high wax ratio caused the high IB. The OSB with the highest wax ratio had higher average MOR, MOE and IB than the OSB with the lowest wax ratio about 13.2, 10.9 and 6.8%, respectively.

For PF/MDI resin, the highest average MOR and MOE in the parallel and perpendicular directions were 25.1 and 3953 MPa in panel F-MDI-0.9/2.9. The highest

Table 3-4.The physical and mechanical properties of 7/16" thick OSB with varied wax ratios.

Panel No.	Density	Thickness	MOR(MPa)			MOE(MPa)			IB(MPa)
	(lb/cu.ft.)	(in.)	parallel(std)	Perpendicular(std)	Par/Per	Parallel(std)	Perpendicular(std)	Par/Per	Value(std)
				PF core resin					
F-PF-(0.9/2.9)	40.1	0.433	25.8 (3.8)	15.1 (3.7)	0.6	5289 (985)	1704 (324)	0.3	0.412 (0.105)
G-PF-(1.3/2.3)	40.3	0.436	28.1 (5.8)	14.1 (2.4)	0.5	5337 (632)	1608 (337)	0.3	0.338 (0.132)
H-PF-(1.7/1.7)	40.8	0.425	28.6 (6.8)	15.3 (4.1)	0.5	5761 (709)	1757 (377)	0.3	0.398 (0.092)
I-PF-(2.1/1.1)	39.3	0.439	28.3 (6.3)	12.3 (2.9)	0.4	5402 (700)	1533 (204)	0.3	0.297 (0.075)
J-PF-(2.5/0.5)	40.7	0.431	28.9 (5.0)	17.5 (4.9)	0.6	6022 (783)	1734 (323)	0.3	0.440 (0.093)
				MDI core resin					
F-MDI-(0.9/2.9)	40.0	0.428	29.1 (8.5)	21.0 (7.2)	0.7	5281 (1712)	2626 (1648)	0.5	0.488 (0.122)
G-MDI-(1.3/2.3)	38.6	0.435	31.8 (4.9)	14.8 (3.9)	0.5	5533 (463)	1598 (249)	0.3	0.429 (0.116)
H-MDI-(1.7/1.7)	39.4	0.431	26.5 (6.8)	17.6 (2.0)	0.7	5669 (778)	1867 (322)	0.3	0.376 (0.141)
I-MDI-(2.1/1.1)	40.4	0.429	31.0 (4.1)	12.9 (2.6)	0.4	6009 (549)	1482 (228)	0.2	0.477 (0.172)
J-MDI-(2.5/0.5)	39.0	0.440	25.2 (5.5)	14.9 (3.6)	0.6	5257 (907)	1594 (91)	0.3	0.419 (0.106)
CSA Standard	-	-	29.0 (-)	12.4 (-)	-	5500 (-)	1500 (-)	-	0.345 (-)

IB value was 0.488 MPa in panel F-MDI-0.9/2.9, which was above the 0.345 MPa requirement based on the CSA 0437 Standard. The OSB with the highest wax ratio had average MOR, MOE and IB lower than the OSB with the lowest wax ratio about 24.9, 15.4 and 16.5%, respectively. From the results, the low wax ratio caused the high MOR, MOE and IB. Theoretically, wax increases improved dimensional stability and resisted water penetration but a high wax content can deteriorate mechanical properties. Wang and Lam (1998) stated that the face-to-core ratio and core structure strongly influence MOE in the parallel direction. Although Wang and Lam (1998)'s study and this study differ, we can conclude that the face-to-core ratio, especially face-to-core wax ratio, influences the bending properties in the parallel direction.

3.5.3 TS, Edge TS and WA

3.5.3.1 Resin Influences

Figure 3-6 showed the comparison of one-inch inside TS, Edge TS and WA of 7/16" thick OSB between resin types. The OSB with MDI as core resin had significantly lower average edge TS, one-inch inside TS and WA than the OSB with PF as core resin after 24-hours water exposure about 13.4, 13.7 and 30.9%, respectively. These results seemed to agree with Brochmann et al (2004)'s finding that the OSB with MDI resin provided better TS than the OSB with PF resin due to a faster and more complete cure. However Brochmann et al (2004)'s study used MDI as both face and core resin. From the results one-inch inside TS was higher than edge TS probably which was different from Gu et al (2003)'s study probably due to the difference in furnish dimension. Lose of fine particles caused reduction of internal stress at the edge. Table 3-5 showed the one-inch inside TS, edge TS and WA of 7/16" thick OSB with varied resin ratios.

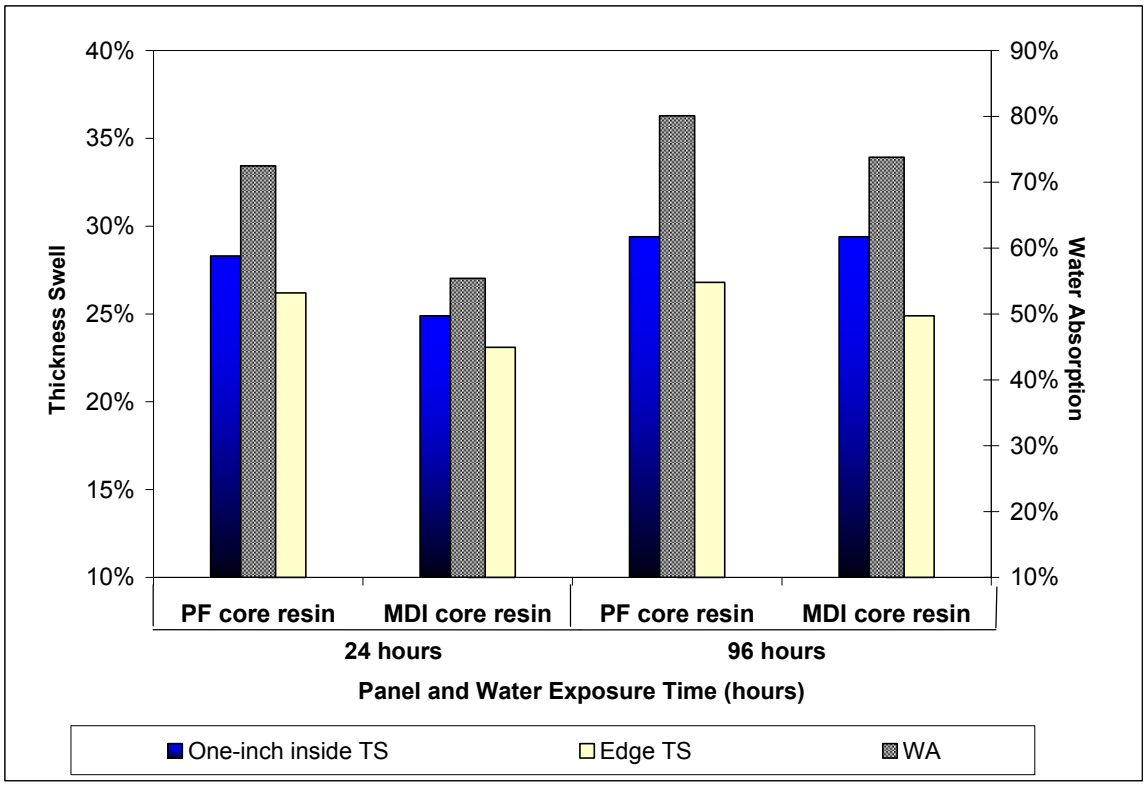

Figure 3-6. Comparison of one-inch inside TS, edge TS and WA of 7/16" thick OSB between resin types.

Table 3-5. The one-inch inside TS, edge TS and WA of 7/16" thick OSB with varied resin ratios.

Board No.	One-inch inside thickness swell		Edge-thickness swell		Water absorption	
	24 hours (std)	96 hours(std)	24 hours(std)	96 hours(std)	24 hours(std)	96 hours(std)
	----------%----------		----------%----------		----------%----------	
			PF core resin			
A-PF-(3.0/5.50)	28.4 (1.2)	30.0 (2.0)	28.1 (2.9)	28.6 (2.5)	73.8 (4.4)	83.3 (3.8)
B-PF-(3.5/4.75)	26.0 (1.4)	27.1 (1.3)	24.5 (1.7)	25.5 (1.3)	75.6 (3.9)	86.5 (4.0)
C-PF-(4.0/4.00)	27.7 (2.4)	29.0 (2.2)	25.5 (2.0)	25.9 (2.1)	70.5 (3.0)	78.4(4.9)
D-PF-(4.5/3.25)	29.1 (2.4)	28.8 (3.9)	27.5 (2.6)	27.5 (3.6)	74.4 (4.7)	84.3 (5.9)
E-PF-(5.0/2.50)	28.3 (1.7)	29.9 (1.2)	25.5 (2.1)	26.2 (1.7)	75.0 (2.9)	84.4 (2.7)
			MDI core resin			
A-MDI-(3.0/5.50)	25.6 (3.0)	28.4 (3.2)	23.8 (2.9)	25.4 (2.8)	53.4 (6.2)	70.0 (6.6)
B-MDI-(3.5/4.75)	26.9 (3.0)	28.9 (3.0)	23.1 (2.4)	24.4 (3.0)	55.9 (4.9)	73.6 (3.6)
C-MDI-(4.0/4.00)	23.2 (1.6)	26.7 (1.0)	22.1 (2.5)	23.5 (3.0)	54.6 (6.4)	72.1(5.7)
D-MDI-(4.5/3.25)	24.2 (1.9)	29.6 (3.9)	21.9 (1.9)	24.1 (3.5)	59.7 (11.1)	80.1(11.2)
E-MDI-(5.0/2.50)	25.9 (2.1)	29.5 (2.0)	23.6 (1.4)	25.3 (1.9)	60.3 (5.9)	76.1(6.4)

For PF/PF resin, the total TS in this study were measured at both one-inch inside TS from each edge and on the edges. The lowest edge TS was 24.5% and 25.5% after 24 and 96-hours water exposure in panel B-PF-3.5/4.75. The lowest one-inch inside TS was 26.0% and 27.1% in panel B-PF-3.50/4.75 after 24 and 96-hours water exposure. The lowest WA was 70.5% and 78.4% in panel C-PF-4.0/4.00 after 24 and 96-hours water exposure. The difference of total thickness swell, one-inch inside TS and edge TS, of the OSB with the highest resin ratio and the lowest resin ratio were very small (0.4 and 0.3%) while the OSB with highest resin ratio had higher WA than the OSB with the lowest resin ratio about 1.6% after 24-hours water exposure.

For PF/MDI resin, the lowest one- inch inside TS was 23.2% and 26.7% in panel C-MDI-4.0/4.00 after 24 and 96-hours water exposure. The lowest edge TS was 21.9% after 24-hours water exposure in panel D-MDI-4.50/3.25 and 23.5% after 96-hours water exposure in panel C-MDI-4.0/4.00. The lowest WA was 53.4% and 70.0% in panel A-MDI-3.0/5.50 after 24 and 96-hours water exposure. The OSB with the highest resin ratio had higher one-inch inside TS and WA than the OSB with the lowest resin ratio about 1.2 and 12.9%, respectively while the OSB with highest resin ratio had lower one-inch inside TS than the OSB with the lowest resin ratio about 0.8% after 24-hours water exposure.

From the results, the resin ratio of the OSB with PF as core resin had an effect on one-inch inside TS and edge TS after 24-hours water exposure but not affect after 96-hours of water exposure. However, the rate of thickness swell decreased with increasing water exposure time. The resin ratio of the OSB with PF as core resin did not affect WA after 24 and 96-hours water exposure because hand forming increases the amount of void volume in mat structure. This result agreeed with Geimer (1982)'s finding that the total

water absorption relied on the ratio of void volume to solid wood and board density. The optimum resin ratio effected one-inches inside TS. The slightly higher resin in the core layer had noticeably better one-inch inside TS. The highest resin content in the core layer did not have the best TS because of the very low resin content at the surface. The best TS occurred on the panel with the highest bending strength and IB. Brochmann et al (2004) stated that face-to-core ratio did not influence TS. This study shows that face-to-core resin ratio influenced both one-inch inside TS and edge TS after 24-hour water exposure in OSB with PF as core resin. Brochmann et al (2004)'s study and this study were different because face-to-core ratio was the ratio of combination of furnish, resin and wax ratio.

3.6.3.2 Wax Influences

Table 3-6 showed one-inch inside TS, edge TS and WA of 7/16" thick OSB with varied wax ratios. For PF/PF resin, the lowest edge TS was 24.5% in panel J-PF-2.5/0.5 after 24-hours water exposure and 25.1% in panel I-PF-2.1/1.1 after 96-hours of water exposure. The lowest one-inch inside TS was 27.7% in panel H-PF-1.7/1.7 after 24-hours water exposure and 27.6% in panel J-PF-2.5/0.5 after 96-hours water exposure. The lowest WA was 70.2% and 75.9% in panel F-PF-0.9/2.9 after 24 and 96-hours water exposure. From the results, the panels with higher wax content in the surface had the lower TS but the panels with higher wax content in the core layer had the lower WA. The OSB with the highest wax ratio had 7.2% of one-inch inside TS and 8.6% of edge TS lower than the OSB with the lowest wax ratio while the OSB with the highest wax ratio had 1.4% of WA higher than the OSB with the lowest wax ratio after 24-hours water exposure.

Table 3-6. The one-inch inside TS, edge TS and WA of 7/16" thick OSB with varied wax ratios.

Board No.	One-inch inside thickness swell		Edge-thickness swell		Water absorption	
	24 hours (std)	96 hours(std)	24 hours(std)	96 hours(std)	24 hours(std)	96 hours(std)
	----------%		----------%		----------%	
			PF core resin			
F-PF-0.9/2.9	28.4 (2.3)	30.0 (2.3)	26.6 (1.8)	28.1 (1.7)	70.2 (4.1)	75.9 (4.1)
G-PF-1.3/2.3	31.7 (3.6)	32.5 (4.9)	30.0 (5.9)	29.2 (6.6)	70.9 (4.2)	76.8 (4.6)
H-PF-1.7/1.7	27.7 (2.4)	29.0 (2.2)	25.5 (2.0)	25.9 (2.1)	70.5 (3.0)	78.4(4.9)
I-PF-2.1/1.1	28.5 (1.2)	30.0 (2.2)	24.6 (2.3)	25.1 (2.1)	72.0 (7.4)	76.5 (7.2)
J-PF-2.5/0.5	26.5 (1.5)	27.6 (1.6)	24.5 (1.1)	25.8 (1.5)	71.2 (2.8)	76.4 (3.2)
			MDI core resin			
F-MDI-0.9/2.9	24.2 (2.7)	29.9 (1.6)	23.7 (4.6)	25.9 (4.5)	50.5 (5.1)	69.5 (13.8)
G-MDI-1.3/2.3	24.0 (3.3)	30.8 (4.3)	20.7 (1.9)	22.7 (1.7)	55.5 (1.7)	74.9 (0.9)
H-MDI-1.7/1.7	25.2 (2.9)	29.5 (2.3)	24.2 (2.6)	26.2 (2.6)	55.5 (3.1)	74.9 (1.6)
I-MDI-2.1/1.1	23.3 (1.7)	29.2 (3.1)	22.9 (2.2)	24.1 (2.3)	49.0 (3.9)	68.0 (4.7)
J-MDI-2.5/0.5	25.6 (2.0)	30.9 (2.3)	25.2 (2.0)	27.2 (2.5)	59.2 (4.9)	78.6 (4.3)

For PF/MDI resin, the lowest one-inch inside TS was 23.3% and 29.2% in panel I-MDI-2.1/1.1 after 24 and 96-hours water exposure. The lowest edge TS were 20.7% and 22.7% in panel G-MDI-1.3/2.3 after 24 and 96-hours water exposure. The lowest WA was 49.0% and 68.0% in panel I-2.1/1.1 after 24 and 96-hours water exposure. The OSB with the highest wax ratio had 5.8% of one-inch inside TS, 6.3% of edge TS and 17.2% of WA higher than the OSB with the lowest wax ratio after 24-hours water exposure.

From the results, the wax ratio had an effect on one-inch inside TS and edge TS after 24-hours water exposure in the OSB with PF as core resin and OSB with MDI as core resin. The OSB with higher wax content in the surface resulted in lower one-inch inside TS and edge TS after 24-hours water exposure. The wax ratio of the OSB with PF and MDI as core resin had an effect on WA after 24-hours water exposure. The OSB with slightly higher wax content in surface had better WA in the OSB with MDI as core resin. Although Brochmann et al (2004) stated that face-to-core material ratio did not influence TS, in this study the face-to-core wax ratio did influence both edge TS and one-inch inside TS. This experiment kept the face-to-core resin ratio constant but varied wax distribution in the face and core layer. The panel with the highest wax content at the surface and the lowest wax content in core layer had better one-inch inside TS and edge TS after 24-hours water exposure because the high wax content at the surface was highly resistant to water penetration. The better TS related to the highest bending strength and IB value because the small amount of total wax content did not significantly deteriorate strength of the OSB panel. Figure 3-7 showed the relationship between edge TS and one-inch inside TS of 7/16” thick OSB. Edge TS was highly correlated to one-inch inside TS.

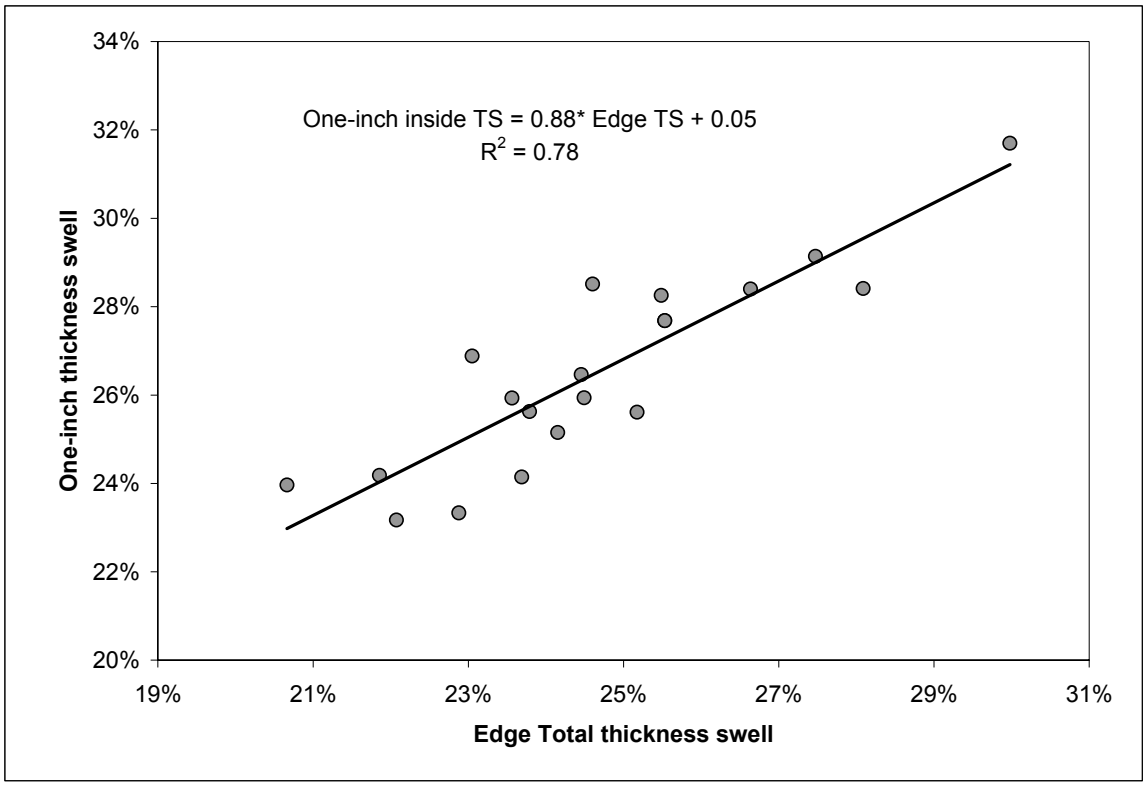

Figure 3-7. Relationship between edge TS and one-inch inside TS of 7/16" thick OSB after 24-hours water exposure.

3.5.4 Layer TS

3.5.4.1 Resin Influences

Layer TS was related to water exposure time, layer location, and vertical density profile. In 7/16" thick panels, the panels were divided into thirteen-0.8 mm thick layers through the panel thickness in order to study the individual layer thickness swell. The shell ratio (the ratio on a weight basis of face materials to core materials) was equal to 60:40 or 30:40:30 (top face: core: bottom face). The face region and core region were separated based on the vertical density profile data by top face, core and bottom face region weight equal to 30, 40 and 30% of the total panel weight, respectively. The top face region covered layers 1 to 3 and part of layer 4. The core region covered part of layer4, layers 5-9 and part of layer 10, and bottom face region covered part of layer 10 and layers 11 to 13.

Tables 3-7 and 3-8 showed the actual and percentage layer TS of 7/16" thick OSB with varied resin ratios. The relative percentage of each panel was calculated to compare the individual layer thickness swells. Theoretically, the total edge thickness swell was equal to the sum of the thickness swell of the individual layers. Figure 3-8 shows comparison of percentage of layer thickness swell of 7/16" thick OSB varied resin ratios of the OSB with PF as core resin. For PF/PF resin, after 24-hours water exposure, the lowest percentage of layer TS at the core layer was about 29%, which put 71% was at the surface in panel A-PF-3.0/3.50. The highest percentage of layer TS at the core layer was 40%, which put 60% at the surface in panel E-PF-5.0/2.50. After 96-hours water exposure, the lowest percentage of layer TS at the core layer was about 32% which put 68% at the surface in panel A-PF-3.0/3.50. The highest percentage of layer TS at the core

Table 3-7. Actual layer thickness swell of 7/16" thick OSB with varied resin ratios.

Sample No.	24 hours water soak			96 hours water soak		
	Top Face (Layer 1-3, Part of layer 4) Value(Std)	Core (Part of Layer 4, Layer 5-9, part of Layer 10) Value(Std)	Bottom Face (Part of layer 10, Layer 11-13) Value(Std)	Top Face (Layer 1-3, Part of layer 4) Value(Std)	Core (Part of Layer 4, Layer 5-9, part of Layer 10) Value(Std)	Bottom Face (Part of layer10, Layer 11-13) Value(Std)
	----------%----------			----------%----------		
			PF core resin			
A-PF-3.0/5.50	31.1(8.0)	25.7(3.6)	25.8(7.7)	31.2(8.5)	27.3(7.4)	25.0(11.8)
B-PF-3.5/4.75	27.2(14.6)	24.9(3.0)	25.5(8.8)	32.4(22.2)	25.7(2.0)	26.2(10.0)
C-PF-4.0/4.00	22.2(5.1)	26.4(2.5)	27.2(2.7)	25.4(6.1)	26.9(5.3)	23.5(2.4)
D-PF-4.5/3.25	26.1(2.8)	32.4(7.7)	28.0(6.4)	28.6(4.4)	31.2(10.0)	27.5(8.6)
E-PF-5.0/2.50	24.8(4.8)	34.1(3.4)	23.7(9.1)	26.0(6.6)	33.8(4.5)	24.0(10.2)
			MDI core resin			
A-MDI-3.0/5.50	21.4(1.6)	28.0(2.8)	24.8(3.7)	22.4(1.3)	28.5(1.8)	25.7(3.9)
B-MDI-3.5/4.75	26.7(8.6)	34.5(9.2)	30.6(6.5)	28.2 (6.4)	37.1(9.4)	31.4(6.6)
C-MDI-4.0/4.00	22.7(2.6)	28.0(3.5)	26.5(7.7)	23.3(2.0)	31.5(3.1)	28.5(6.3)
D-MDI-4.5/3.25	26.0(3.1)	32.1(2.6)	30.4(4.7)	26.7(2.9)	33.4(3.3)	30.4(5.6)
E-MDI-5.0/2.50	22.8(2.5)	28.2(3.2)	29.1(6.6)	23.8(1.8)	30.3(4.5)	28.4(7.1)

Table 3-8. Percentage of layer thickness swell of 7/16" thick OSB with varied resin ratios.

Sample No.	24 hours water soak			96 hours water soak		
	Top Face (Layers 1-3, Part of layer 4) Value(Std)	Core (Part of Layer 4, Layers 5-9, part of Layer 10) Value(Std)	Bottom Face (Part of layer 10, Layers 11-13) Value(Std)	Top Face (Layers 1-3, Part of layer 4) Value(Std)	Core (Part of Layer 4, Layer s 5-9, part of Layer 10) Value(Std)	Bottom Face (Part of layer 10, Layers 11-13) Value(Std)
	----------%			----------%		
			PF core resin			
A-PF-3.0/5.50	40.8(6.6)	29.4(4.4)	29.8(7.7)	41.3(10.1)	31.8(3.5)	26.9(9.2)
B-PF-3.5/4.75	38.0(8.5)	31.7(4.7)	30.3(8.2)	40.5(11.5)	30.9(6.3)	28.6(9.1)
C-PF-4.0/4.00	32.6(4.8)	30.8(3.4)	36.6(3.3)	36.5(5.7)	31.8(4.1)	31.7(4.1)
D-PF-4.5/3.25	32.6(3.6)	38.1(4.5)	29.3(4.7)	36.2(9.4)	35.7(8.2)	28.1(5.9)
E-PF-5.0/2.50	32.5(4.3)	39.9(8.8)	27.6(8.6)	33.4(6.0)	39.2(9.0)	27.3(8.7)
			MDI core resin			
A-MDI-3.0/5.50	31.1(3.0)	38.7(1.3)	30.2(2.3)	31.3(2.6)	38.4(2.0)	30.3(2.9)
B-MDI-3.5/4.75	31.9(4.6)	38.2(7.6)	29.9(5.6)	32.2(4.0)	38.7(6.7)	29.1(5.5)
C-MDI-4.0/4.00	33.2(2.8)	29.5(4.4)	37.3(6.4)	31.4(3.3)	30.8(4.5)	37.8(5.4)
D-MDI-4.5/3.25	31.3(2.6)	39.5(2.0)	29.2(2.6)	31.6(3.3)	40.0(2.2)	28.4(2.2)
E-MDI-5.0/2.50	30.6(4.1)	38.1(2.9)	31.3(5.3)	30.9(4.1)	39.7(4.0)	29.4(5.1)

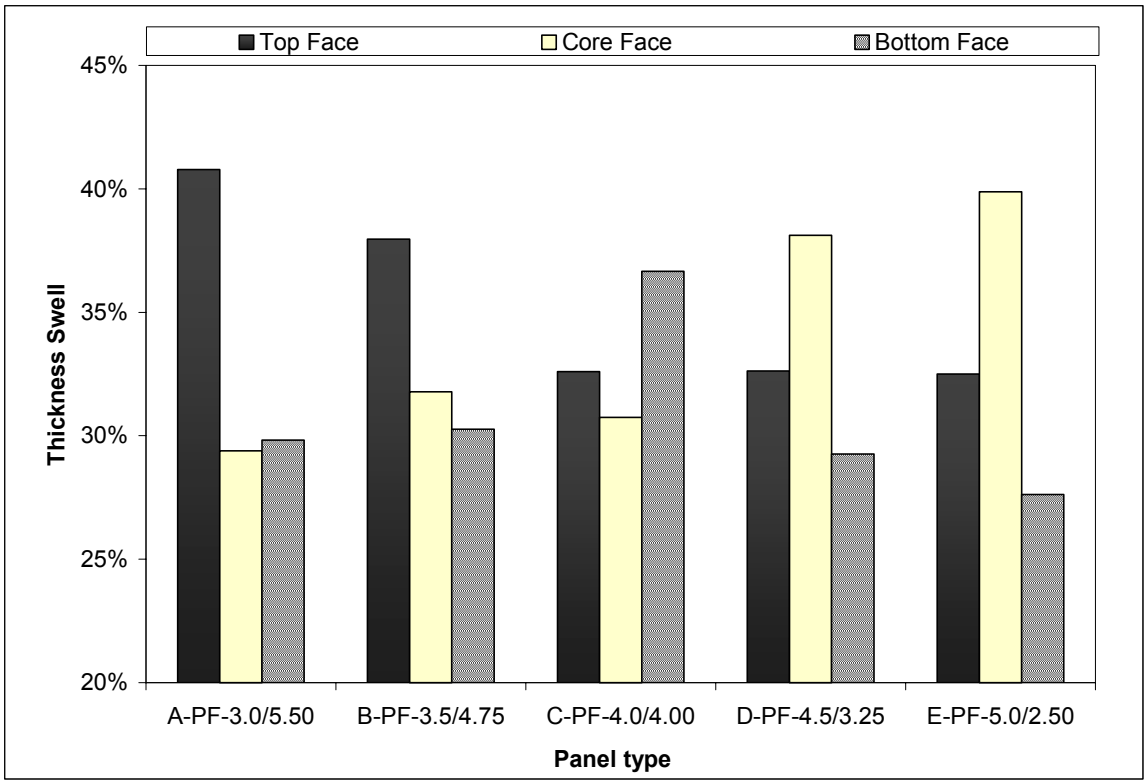

Figure 3-8. Comparison of percentage of layer thickness swell of 7/16" thick OSB with varied resin ratios of OSB with PF as core resin after 24-hours water exposure.

layer was about 39%, which puts 61% at the surface in panel A-PF-3.0/5.50. From the results, adding more resin in the surface can decrease thickness swell at the surface but increases thickness swell in core layer because of the decrease in resin content at core layer. Gu et al (2004) recommended that TS at the surface layer played the key role in reducing total thickness swell. A lower thickness swell at the surface layer, contributing to total thickness swell, was more desirable. Considering total edge TS and layer TS, the lowest edge TS after 24-hours water exposure was 24.5% in panel B-PF-3.5/4.75. Therefore, to have the lowest total edge TS, the panel should have thickness swell less than 68% at surface and 32% at core layer. Thickness swell at the top face contributed to total thickness swell more than that at the bottom face and thickness swell at the surface contributed to total thickness swell more than that at the core layer. In addition, these results agreed with Gu et al (2004)'s finding that the thickness swell of the surface and core layer contributed to total thickness swell and tended to have a proportion equal to the shell ratio when water exposure time increased. However, a slight difference occurred. More resin at the surface, resulted in less thickness swell at surface and more resin at the core layer resulted in less thickness swell at the core layer.

For PF/MDI resin, after 24-hours water exposure, the lowest percentage of thickness swell at the core layer that contributed to total thickness swell was about 30% in panel C-MDI-4.0/4.00. The MDI affected thickness swell at the core layer after 24 and 96-hours water exposure. To determine TS of the OSB with MDI as core resin, the appropriate water exposure time should be used. Many factories in USA and Canada tested 96-hours water exposure. Considered with total edge TS, the lowest total edge TS

was 21.9% in panel D-MDI-4.5/3.25. To have the lowest total edge TS, the panel should have the lowest thickness swell in the surface. Total thickness swell should be less than 59% at surface.

3.5.4.1 Wax Influences

Although wax can reduce mechanical properties, it can also improve dimensional stability, especially thickness swell. Tables 3-9 and 3-10 showed the actual and percentage layer TS of 7/16" thick OSB with varied wax ratios. For PF/PF resin, after 24-hours water exposure, the lowest percentage of layer thickness swell was about 29% in the core layer in panel I-PF-2.1/1.1 and about 71% in the surface. The highest percentage of layer thickness swell was 40% in the core layer in panel J-PF-2.5/0.5 and F-PF-0.9/2.9 and about 60% in the surface. Considering the total edge TS and layer TS, the lowest total edge TS was 24.5% in panel J-PF-2.50/0.50. Therefore, to have the low total edge TS, the thickness swell at the surface contributing to total thickness swell should be less than 40% at the surface and 60% at the core layer. Extreme amounts of wax either in the surface or core layer can decrease total thickness swell in the core layer likely because water cannot penetrate the extreme amount of wax.

For PF/MDI resin, after 24-hours water exposure, the lowest percentage of TS was about 33% in the core layer and 67% in the surface in panels I-MDI-2.1/1.1. The highest percentage of TS was about 43% in the core layer and 57% in the surface in panel H-MDI-1.7/1.7. Considering with the total edge TS and layer TS, the lowest total edge TS was 20.7% in panel G-MDI-1.3/2.3. Therefore, to have the lowest total edge TS, the contribution of thickness swell at the surface should be less than 62% at the surface and 38% at the core. The high wax content in the core layer resulted in the lowest TS in the

Table 3-9. Actual layer thickness swell of 7/16" thick OSB with varied wax ratios.

Sample No.	24 hours water soak			96 hours water soak		
	Top Face (Layers 1-3, Part of layer 4) Value(Std)	Core (Part of Layer 4, Layers 5-9, part of Layer 10) Value(Std)	Bottom Face (Part of layer 10, Layers 11-13) Value(Std)	Top Face (Layers 1-3, Part of layer 4) Value(Std)	Core (Part of Layer 4, Layers 5-9, part of Layer 10) Value(Std)	Bottom Face (Part of layer 10, Layers 11-13) Value(Std)
	%			%		
			PF core resin			
F-PF-0.9/2.9	21.1(2.8)	25.7(2.7)	22.8(5.2)	22.7(3.2)	27.2(5.4)	23.8(7.2)
G-PF-1.3/2.3	20.7(3.8)	23.0(2.3)	25.9(4.4)	22.4(4.1)	24.5(4.6)	26.8(4.2)
H-PF-1.7/1.7	23.3(5.8)	20.0(4.2)	25.6(5.4)	24.0(7.0)	23.1(4.2)	27.0(5.1)
I-PF-2.1/1.1	21.6(4.2)	17.9(4.6)	28.7(3.1)	23.5(4.6)	19.2(5.5)	31.7(4.7)
J-PF-2.5/0.5	20.7(4.3)	25.6(5.0)	23.8(4.2)	23.6(3.7)	28.0(4.6)	24.1(5.1)
			MDI core resin			
F-MDI-0.9/2.9	22.3(5.2)	24.6(7.3)	21.8(6.5)	23.0(6.2)	28.6(7.8)	24.4(6.4)
G-MDI-1.3/2.3	20.7(4.3)	25.6(4.1)	24.0(6.5)	21.9(5.1)	28.3(4.5)	23.9(6.4)
H-MDI-1.7/1.7	20.5(5.4)	26.9(4.7)	24.4(7.7)	21.2(6.1)	29.1(5.0)	23.1(9.4)
I-MDI-2.1/1.1	27.1(5.9)	22.8(6.3)	22.5(6.4)	29.1(5.2)	25.2(6.1)	24.5(6.7)
J-MDI-2.5/0.5	24.7(3.7)	24.8(3.3)	25.3(3.7)	25.6(4.8)	27.4(3.6)	25.6(3.7)

Table 3-10. Percentage of layer thickness swell of 7/16" thick OSB with varied wax ratios.

Sample No.	24 hours water soak			96 hours water soak		
	Top Face (Layers 1-3, Part of layer 4) Value(Std)	Core (Part of Layer 4, Layers 5-9, part of Layer 10) Value(Std)	Bottom Face (Part of layer 10, Layers 11-13) Value(Std)	Top Face (Layers 1-3, Part of layer 4) Value(Std)	Core (Part of Layer 4, Layers 5-9, part of Layer 10) Value(Std)	Bottom Face (Part of layer 10, Layers 11-13) Value(Std)
	----------%			----------%		
			PF core resin			
F-PF-0.9/2.9	34.2(4.8)	40.0(4.8)	25.8(4.2)	34.7(5.4)	39.8(5.8)	25.5(5.4)
G-PF-1.3/2.3	32.7(6.0)	35.8(2.6)	31.5(5.9)	33.5(6.6)	35.6(3.6)	30.8(5.4)
H-PF-1.7/1.7	37.2(6.9)	33.4(5.1)	29.4(3.2)	35.4(8.7)	35.5(6.2)	29.1(4.4)
I-PF-2.1/1.1	34.1(4.0)	28.8(4.6)	37.1(2.5)	34.0(4.2)	28.4(4.6)	37.6(3.1)
J-PF-2.5/0.5	32.1(5.1)	40.0(3.3)	27.9(2.4)	33.6(3.8)	40.0(3.1)	26.4(2.4)
			MDI core resin			
F-MDI-0.9/2.9	34.0(5.5)	38.2(4.4)	27.8(6.7)	31.5(5.5)	40.2(3.2)	28.3(7.7)
G-MDI-1.3/2.3	31.8(3.3)	37.9(5.3)	30.3(5.0)	31.7(2.9)	39.6(6.4)	28.7(5.0)
H-MDI-1.7/1.7	29.8(4.4)	43.0(9.6)	27.2(5.6)	29.5(3.5)	45.3(9.4)	25.2(6.7)
I-MDI-2.1/1.1	38.6(4.3)	33.3(6.4)	28.1(7.2)	38.4(3.3)	33.6(6.5)	28.0(6.8)
J-MDI-2.5/0.5	34.1(4.5)	34.1(3.1)	31.8(4.3)	33.6(5.7)	35.8(3.4)	30.6(4.9)

core layer and the high wax content in the surface layer resulted in the lowest TS in the surface layer. The highest wax content in the surface resulted in the lowest TS in face layer but high TS in core layer. To have the lowest TS, an extremely high wax content in face or core was considered. However, extremely high wax content at surface gave better TS because high TS at the surface contributed most to total TS.

3.6 Conclusion

This study found that face and core variables affected laboratory made OSB. Resin and wax ratio affected mechanical properties and dimensional stability of OSB. The MOR and MOE of laboratory made OSB panels were improved as the resin ratio increased, when tested parallel to the face alignment in the OSB with PF as core resin. For OSB with MDI as core resin, the MOR and MOE were improved as the resin ratio increased in both parallel and perpendicular directions. Because IB was more sensitive to resin distribution and resin procure, the resin ratio had slightly affected IB. One-inch inside TS and edge TS decreased as the resin ratio increased in the OSB. However, the increase of wax ratio can decrease one-inch inside TS, edge TS but it had slightly affected WA. The MOR, MOE and IB in both parallel and perpendicular direction were improved as the wax ratio increased in the OSB with PF as core resin. However, the MOR, MOE and IB in both parallel and perpendicular directions were improved as the wax ratio decreased in the OSB with MDI as core resin. Resin ratio and wax ratio affected face and core TS. Higher resin and wax ratio can decrease TS.

CHAPTER 4

INFLUENCE OF RESIN AND WAX RATIO ON 23/32" THICK OSB

4.1 Introduction

Oriented Strandboard (OSB) is usually used for sheathing and flooring application. Different purpose of application requires different properties. The 7/16" thick panels are used for sheathing and 23/32" thickness panel are used for flooring. Therefore, different behaviors in hot pressing occur at different panel thickness. This chapter focuses on the influence of resin ratio, wax ratio and wax loading on flooring product properties, especially thickness swell using traditional and optical methods.

4.2 Experimental Method

4.2.1 Materials

Commercial southern pine furnish was procured from an OSB mill. The furnish was kept at different moisture contents (8-9% for face and 4-5% for core layer). Commercial emulsion wax was procured from Borden Chemical Co. with 58.9% solid content and 82 centipoises. PF resin was procured from Dynea USA Inc. with 44.6% solid content and 30 centipoises of viscosity for the face layer and 44.5% of solid content and 145 centipoises of viscosity for the core layer.

4.2.2 Experimental Design

This experiment was designed to study the effect of resin ratio and wax ratio on panel properties for 23/32" thick OSB. The commercial emulsion wax was applied to the furnish at a total rate of 1.50% per dry wood weight in a rotary blender and PF resin was applied to the furnish at a total rate of 4.5% per dry wood weight in a rotary blender. Different resin and wax content were applied to the furnish used for the face and core

layers. The detailed combinations of resin ratio, wax ratio and wax content were listed in Tables 4-1 and 4-2.

4.2.3 Panel Fabrication

The same commercial southern pine furnish was used to make twenty-six OSB panels. There were two replications. A commercial liquid phenol formaldehyde resin and wax were applied to the furnish at the rate shown in Tables 4-1 and 4-2. The target panel size was 34 by 34 by 23/32 inches, which was trimmed to 30 x 30 inches. The target panel density was 40 lb./cu.ft. The three-layer mat was manually formed in the forming box in different orientation. The mat was pressed at a platen temperature of 204°C, a pressing cycle of 500 seconds and press closure rate of 20 second (from initial contact of the mat with the upper platen until final position was reached). Each mat had a shell ratio of 55:45 (the ratio on a weight basis of face materials to core materials). A 1.6 mm thick aluminium caul was used on the top and bottom of the mat during pressing. The top face of each panel was marked immediately after pressing.

4.2.4 Panel Testing

Testing specimens were cut from the 30" x 30" panel after trimming the edge. The cutting diagram for testing specimens from 2 replications of the 30" x 30" panel was shown in Figure 4-1. Two 6-by-6 inches thickness swelling (TS) and six 2-by-2 inches density profile specimens were obtained from each panel. A commercial densitometer (QMS Density Profile System QDP-01X) was used to measure the vertical density profiles. The average density profile was calculated from ten samples from each panel. Two specimens for the parallel MOR/MOE test, two specimens for the perpendicular MOR/ MOE test, ten specimens for VDP test or IB test were prepared from each panel

Table 4-1. Experimental design of 23/32" thick OSB for resin influences.

Panel No.	Resin content		
	Face	Core	Total
	……%.....		
	1.50% total wax loading		
K-3.55/5.65	3.55	5.65	4.50
L-4.05/5.05	4.05	5.05	4.50
M-4.50/4.50	4.50	4.50	4.50
N-4.95/3.95	4.95	3.95	4.50
O-5.40/3.40	5.40	3.40	4.50

Table 4-2. Experimental design of 23/32" thick OSB for wax influences.

Panel No.	Wax content		
	Face	Core	Total
	……%.....		
	4.50% total resin loading		
P-1.05/2.05	1.05	2.05	1.50
Q-1.32/1.72	1.32	1.72	1.50
M-1.50/1.50	1.50	1.50	1.50
R-1.68/1.28	1.68	1.28	1.50
S-1.95/0.95	1.95	0.95	1.50
T-1.50/0.50	1.50	0.50	1.05
U-1.50/1.00	1.50	1.00	1.28
V-0.50/1.50	0.50	1.50	0.95
W-1.00/1.50	1.00	1.50	1.23

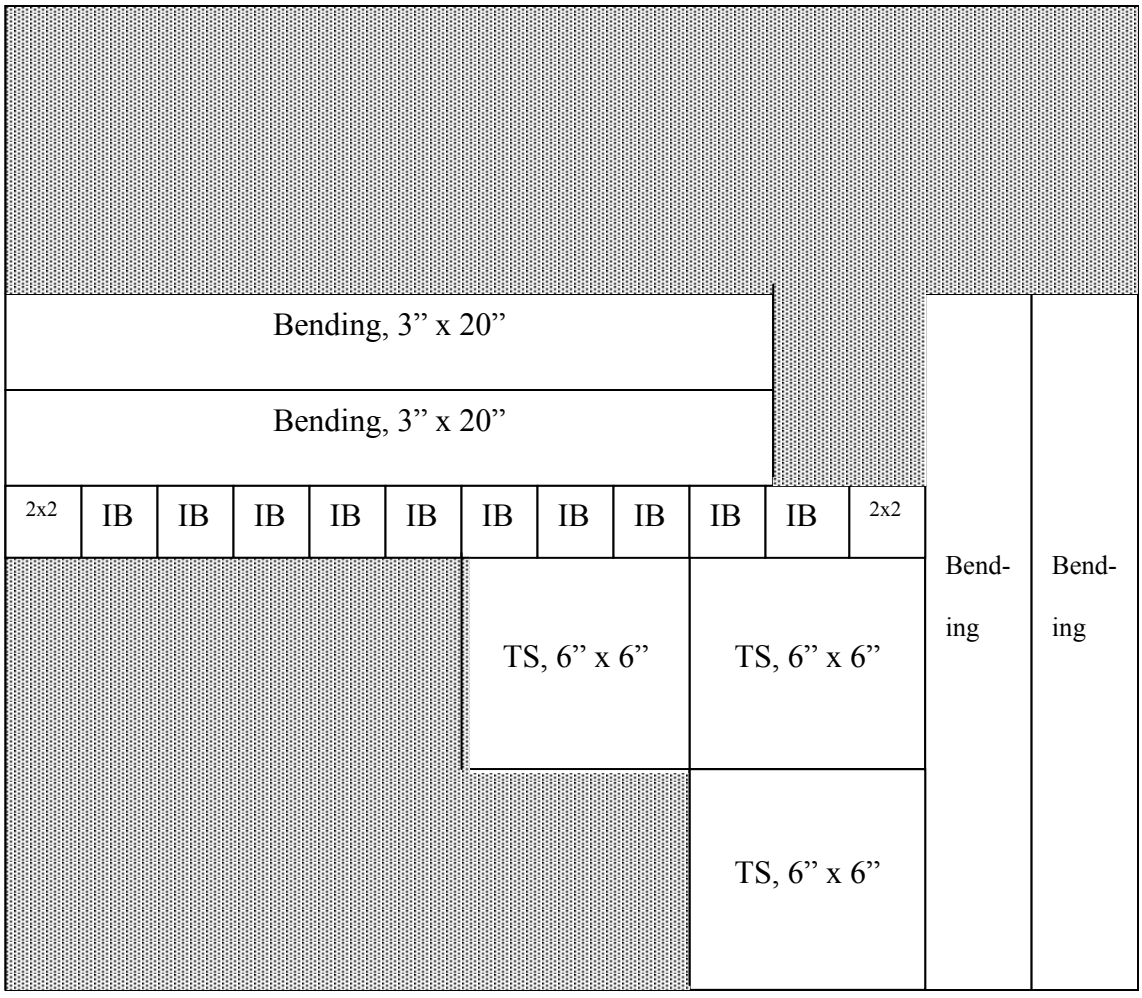

Figure 4-1. Cutting diagram for 23/32” thick OSB.

The MOR/MOE test was performed in accordance with CSA 0437 Series-93 Standards on OSB and Waferboard 5.4.1. The IB test was performed in accordance with CSA 0437 Series-93 Standard on OSB and Waferboard 5.2.1. Layer thickness swell was measured from each specimen after water exposure times of 8, 24 and 96 hours. The nondestructive optical technique was used to determined thickness swell of 21 discrete layers within intact samples of the panels (Wang and Winistorfer, 2000b). The detailed methodology was explained in Chapter 3. ASTM standard technique was used for measuring the one-inch inside total thickness swell, water absorption and edge thickness swell after water exposure times of 8, 24 and 96 hours.

4.3 Results and Discussions

4.3.1 Panel Density and Vertical Density Profile

The VDP of each panel was shown in Figure 4-2. The target average density was 40 lb./cu.ft. From Figure 4-2, the shape of VDP of each panel is identical. However, there are slight differences in each zone. All panels showed a very nice and steep density profile (high density faces relative to the lower density core. The higher wax and resin content affects pressing ease due to higher moisture content and moisture flow. Due to the same pressing schedule, the VDP of each panel tends to have the same pattern.

4.3.2 Mechanical Properties (MOR & MOE and IB)

4.3.2.1 Resin Influences

Table 4-3 showed the physical and mechanical properties of 23/32" thick OSB with varied resin ratios of the OSB with PF as core resin. For PF/PF resin, the highest IB was 0.477 MPa in panel M-4.50/4.50 and was likely due to the high overall density and high core density. The second highest IB strength was 0.472 MPa in panel K-3.55/5.65

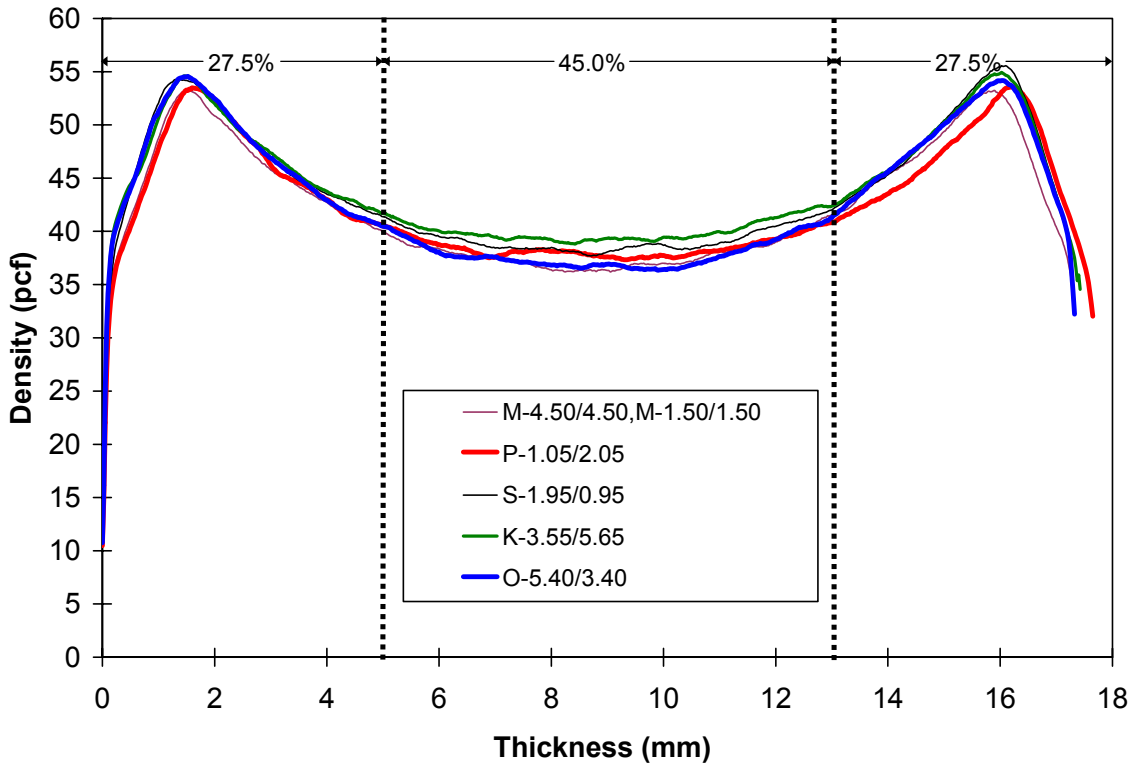

Figure 4-2. The VDP of 23/32" thick OSB with varied resin and wax ratios.

Table 4-3. The physical and mechanical properties of 23/32" thick OSB with varied resin ratios.

Board No.	Density	Thickness	MOR(MPa)			MOE(MPa)			IB(MPa)
	(lb/cu.ft.)	(in.)	Parallel(Std)	Perpendicular(Std)	Par/Per	Parallel(Std)	Perpendicular(Std)	Par/Per	Value(Std)
K-3.55/5.65	40.9	0.717	27.8(1.8)	10.0(1.8)	2.8	5852(281)	1728(101)	3.4	0.472(0.071)
L-4.05/5.05	40.4	0.710	23.6(4.7)	13.3(6.2)	1.8	5307(641)	1977(218)	2.7	0.405(0.050)
M-4.50/4.50	41.4	0.698	20.2(2.2)	12.5(5.7)	1.6	4889(180)	2181(697)	2.2	0.477(0.070)
N-4.95/3.95	40.6	0.710	26.8(3.7)	11.3(2.0)	2.4	5792(865)	2127(101)	2.7	0.360(0.110)
O-5.40/3.40	40.5	0.708	23.0(9.0)	12.3(3.7)	1.9	4920(1584)	2265(698)	2.2	0.370(0.072)
CSA Standard	-	-	29.0 (-)	12.4(-)	-	5500(-)	1500(-)	-	0.345(-)

due to the high core density and high resin content in core layer. The highest MOR and MOE in parallel direction were 27.8 MPa and 5852 MPa in panel K-3.55/5.65, respectively. The highest MOR in perpendicular direction was 13.3 MPa in panel L-4.05/5.05. The highest MOE in perpendicular direction was 2265 MPa in panel O-5.40/3.40. The OSB with the highest resin ratio had 6.8% of average MOR, 5.5% of average MOE and 27.6% of IB lower than the OSB with the lowest resin ratio. Adding more resin in the core layer tended to improve bending MOR and MOE in the parallel and perpendicular directions. Theoretically, higher resin content caused higher strength properties. The influence of orientation and forming uniform had high effect on mechanical properties. From the results, the appropriate combination of resin content in the face and core layers resulted in good strength properties of OSB. An extreme amount of resin in either the face or the core layers did not improve strength properties, especially in the parallel direction. Although PF resin influence on IB values seemed particularly strong on the core layer, IB tests results were generally more variable and more sensitive to resin precure, resin distribution, particle size, forming variation and other process variables. However, the IB failure did not always occur at mid-plane thickness of IB specimens. Similarly, the high-density surface layer did not always produce the highest IB values, especially for OSB. The limited number of specimens used to determine the layer IB profile prevented statistical analysis of how many failures would occur in which layer. In the future, a larger number of specimens should be considered.

4.3.2.2 Wax Influences

Table 4-4 showed the physical and mechanical properties of 23/32" thick OSB with varied wax ratios and wax contents of the OSB with PF as core resin. For PF/PF

Table 4-4.The physical and mechanical properties of 23/32" thick OSB with varied wax ratios and contents.

Board No.	Density	thickness	MOR(MPa)			MOE(MPa)			IB(MPa)
	(lb/cu.ft.)	(in.)	Parallel(Std)	Perpendicular(Std)	Par/Per	Parallel(Std)	Perpendicular(Std)	Par/Per	Value(Std)
P-1.05/2.05	39.5	0.705	25.1(4.3)	11.5(1.1)	2.2	5193(456)	2177(214)	2.4	0.303(0.083)
Q-1.32/1.72	40.6	0.698	24.3(2.8)	10.3(1.0)	2.4	5603(532)	1891(89)	3.0	0.355(0.071)
M-1.50/1.50	41.4	0.698	20.2(2.2)	12.5(5.7)	1.6	4889(180)	2181(697)	2.2	0.477(0.070)
R-1.68/1.28	40.6	0.716	25.4(3.1)	13.2(3.4)	1.9	5774(577)	2432(200)	2.4	0.409(0.050)
S-1.95/0.95	40.2	0.709	18.2(2.8)	13.9(3.7)	1.3	4304(438)	2418(586)	1.8	0.426(0.066)
T-1.50/0.50	40.0	0.703	20.9(2.7)	14.7(3.2)	1.4	4531(488)	2659(304)	1.7	0.455(0.121)
U-1.50/1.00	39.6	0.709	13.6(2.7)	10.2(1.2)	1.3	4172(625)	2092(339)	2.0	0.269(0.076)
M-1.50/1.50	41.4	0.698	20.2(2.2)	12.5(5.7)	1.6	4889(180)	2181(697)	2.2	0.477(0.070)
V-0.50/1.50	39.5	0.717	18.8(2.7)	17.3(2.5)	1.1	4789(759)	2960(875)	1.6	0.364(0.083)
W-1.00/1.50	40.3	0.705	18.6(3.3)	14.1(2.0)	1.3	4517(508)	2409(278)	1.9	0.393(0.065)

resin, the highest IB strength was 0.477 MPa in panel M-1.50/1.50 and was likely due to the high overall density and high core density. The second highest IB strength was 0.426 MPa in panel S-1.95/0.95 and was likely due to the low wax content in the core layer. The highest MOR and MOE in the parallel direction were 25.1 MPa in panel P-1.05/2.05 and 5603 MPa in panel Q-1.05/2.05. The highest MOR and MOE in the perpendicular direction were 13.9 and 2418 MPa in panel S-1.95/0.95. However, the average MOR of the parallel and perpendicular directions was 19.3 MPa in panel P-1.05/2.05. The average MOE of parallel and perpendicular directions was 4103 MPa in panel P-1.05/2.05. The OSB with the highest wax ratio had 13.7% of average MOR, 9.6% of average MOE lower than the OSB with the lowest wax ratio while the OSB with highest wax ratio had 40.6% of IB higher than the OSB with the lowest wax ratio. Generally, higher wax loading can deteriorate the mechanical properties. From the results, wax loading in the core layer had a larger influence on IB than wax loading in surface. Adding less wax in surface tended to result in better MOR and MOE in the perpendicular direction. Wang and Lam (1998) stated face-to-core ratio and core structure had a strong affect on MOE in the parallel direction but these roles were limited for IB and TS. Comparing Wang and Lam (1998)'s finding, and this study, it was concluded that wax ratio influenced MOR and MOE in the parallel direction. Face-to-core ratio and core structure influenced MOE in the parallel direction. However Wang and Lam (1998) varied the face-to-core ratio of wax, resin and amount of flake in the mat but this study varied only resin or wax ratio. For varied wax content, the highest MOR and MOE in the parallel direction were 20.9 MPa in panel T-1.50/0.50 and 4889 MPa in panel M-1.50/1.50. In the perpendicular direction, the highest MOR and MOE were 17.3 and 4889 MPa in panel V-0.50/1.50. The

average MOR of the parallel and perpendicular directions was 18.1 MPa in panel V-0.50/1.50. The average MOE of the parallel and perpendicular directions was 3875 MPa in panel V-0.50/1.50. The highest IB value was 0.477 MPa in panel M-1.50/1.50 and was likely due to the high average density. The second highest IB value was 0.455 in panel T-1.50/0.50. From the results, adding less wax in the surface tended to result in better MOR and MOE in both the parallel and perpendicular directions. Adding less wax in core layer tended to result in better IB values. Also panel V-0.50/1.50 had the lowest total wax content of 0.95%. From the results, the lower the total wax content, the higher the mechanical properties.

4.3.3 TS, Edge TS and WA

4.3.3.1 Resin Influences

Table 4-5 showed one-inch inside TS, edge TS and WA of 23/32" thick OSB with varied resin ratios of the OSB with PF as core resin. Both total edge thickness swell and one-inch inside thickness swell were reported. After 8-hours water exposure, panels N-4.95/3.95 and O-5.40/3.40 had 6.4% and 6.7% of one-inch inside TS, 14.5% and 13.7% of edge TS and 17.4% and 15.2% of water absorption, respectively. After 24-hours water exposure, panel L-4.05/5.05 tended to be the lowest TS. After 96-hours water exposure, panel O-5.40/3.40 had the lowest WA at 56%. The OSB with the highest resin ratio had 30.5% of one-inch inside TS, 4.3% of edge TS and 18.6% of WA lower than the OSB with the lowest resin ratio after 24-hours water exposure. Brochmann et al (2004) stated that face-to-core ratio did not affect TS. This study probably agreed with that but this study varied resin and wax ratio and did not vary the furnish ratio. However, this study supported Xu and Winistorfer's study (1995), which stated that efforts to improve

Table 4-5. The one-inch inside TS, edge TS and WA of 23/32" thick OSB with varied resin ratios.

Board No.	One-inch inside TS			Edge TS			WA		
	8 hours(std)	24 hours(std)	96 hours(std)	8 hours(std)	24 hours(std)	96 hours(std)	8 hours(std)	24 hours(std)	96 hours(std)
L-4.05/5.05	7.6(0.2)	15.4(1.7)	25.5(2.3)	14.8(1.7)	21.7(2.6)	28.0(2.9)	22.6(2.7)	36.4(2.2)	66.1(1.7)
N-4.95/3.95	6.4(0.3)	11.6(1.0)	24.8(1.6)	14.5(1.5)	20.6(1.2)	28.4(0.9)	17.4(1.2)	30.5(1.7)	58.6(1.1)
M-4.50/4.50	8.4(2.1)	14.0(4.0)	24.2(3.6)	15.7(3.9)	20.5(3.3)	27.4(1.9)	21.3(7.7)	41.1(7.0)	70.9(6.7)
K-3.55/5.65	7.5(1.3)	14.8(4.0)	27.6(2.7)	15.2(3.3)	21.9(3.3)	28.9(2.0)	17.8(4.1)	32.1(7.3)	60.5(7.0)
O-5.40/3.40	6.7(1.2)	11.8(4.1)	26.1(3.7)	13.7(1.7)	20.8(1.9)	30.8(0.9)	15.2(3.7)	30.7(9.6)	56.7(7.2)

dimensional stability should be focused on stabilizing the surface layers of OSB and MDF. From the results, resin ratio influenced WA after 96-hours water exposure but did not affect WA after 8 and 24-hours water exposure. Winistorfer and Xu (1996) stated that water absorption continuously increased even after thickness swell of individual layers had reached its maximum. Geimer (1982) mentioned that total water absorption depended upon the ratio of void volume to solid wood and board density. From the results it was believed that before 96-hours water exposure, the water will penetrate and filled in the void volume of wood and after 96-hours water exposure, the water will penetrate to the furnish.

4.3.3.2 Wax Influences

Table 4-6 showed one-inch inside TS, edge TS and WA of 23/32" thick OSB with varied wax ratios and contents of the OSB with PF as core resin. After 8, 24 and 96-hours water exposure, the lowest one-inch inside TS and edge TS were 4.4% and 10.5%, 18.3% and 11.0%, 17.0% and 21.8%, respectively in panel P-1.05/2.05 likely because wax can resist water penetration temporarily. The lowest WA was 21.3%, 41.1% and 60.4% after 8, 24 and 96-hours water exposure in panels M-1.50/1.50, M- 1.50/1.50 and P-1.05/2.05, respectively. The OSB with the highest wax ratio had 35.9% of one-inch inside TS and 22.9% of edge TS higher than the OSB with the lowest wax ratio while the OSB with the highest wax ratio had 3.0% of WA lower than OSB with the lowest wax ratio after 24-hours water exposure.

For varied wax content, the lowest one-inch inside TS and edge TS after 24-hours water exposure were about 11% and 17% in panels V-0.50/1.50 and W-1.00/1.50. The lowest WA after 24-hours water exposure was 43% in panels T-1.50/0.50 and U-

Table 4-6. The one-inch inside TS, edge TS and WA of 23/32" thick OSB with varied wax ratios and contents.

Board No.	One-inch inside TS			Edge TS			WA		
	8 hours(std)	24 hours(std)	96 hours(std)	8 hours(std)	24 hours(std)	96 hours(std)	8 hours(std)	24 hours(std)	96 hours(std)
R-1.68/1.28	4.7(1.2)	10.3(1.9)	19.0(1.6)	10.7(0.8)	16.6(1.1)	21.7(1.4)	22.8(2.4)	44.2(4.8)	62.5(5.1)
Q-1.32/1.72	10.1(1.5)	17.0(2.0)	25.8(0.6)	16.6(1.9)	22.1(0.8)	26.5(1.4)	27.2(5.9)	49.4(7.7)	68.1(6.8)
M-1.50/1.50	8.4(2.1)	14.0(4.0)	24.2(3.6)	15.7(3.9)	20.5(3.3)	27.4(1.9)	21.3(7.7)	41.1(7.0)	70.9(6.7)
P-1.05/2.05	4.4(1.0)	10.5(1.3)	18.3(0.6)	11.0(1.1)	17.0(1.3)	21.8(1.2)	22.5(4.1)	43.7(5.3)	60.3(6.5)
S-1.95/0.95	7.3(1.6)	14.0(2.0)	22.8(2.2)	14.3(2.1)	20.4(2.9)	25.5(2.9)	22.6(1.4)	42.9(0.9)	60.8(2.4)
T-1.50/0.50	4.6(1.7)	13.2(2.0)	24.1(1.8)	12.8(1.7)	19.9(2.9)	25.5(3.6)	25.8(5.5)	43.4(8.1)	72.6(6.8)
U-1.50/1.00	5.4(2.2)	12.4(3.4)	21.2(1.5)	12.4(2.1)	19.4(1.9)	24.5(1.5)	27.2(7.4)	43.0(9.9)	71.7(9.6)
M-1.50/1.50	8.4(2.1)	14.0(4.0)	24.2(3.6)	15.7(3.9)	20.5(3.3)	27.4(1.9)	21.3(7.7)	41.1(7.0)	70.9(6.7)
V-0.50/1.50	5.0(1.1)	11.1(1.6)	19.0(2.7)	11.9(1.6)	17.2(1.0)	21.4(2.1)	30.9(7.4)	46.2(8.2)	73.1(7.8)
W-1.00/1.50	4.7(1.3)	11.3(0.8)	18.8(1.6)	10.4(1.1)	17.2(1.7)	21.5(3.8)	28.1(6.1)	45.3(7.9)	73.5(7.8)

1.50/1.00. Generally, wax as a sizing agent was used to provide the finished products with resistance to aqueous penetration. Wax emulsion provided excellent water holdout and dimensional stability in the board upon wetting. The water repellency provided had practically no effect upon dimension changes or water absorption of boards exposed to equilibrium conditions. Such repellency was only the case for water, as the absorption of water vapor was not hindered. Many investigators found that the addition of wax retarded water absorption temporarily, but had little effect when the board was exposed to equilibrium conditions by water soaking or high humidity. Another function of wax emulsion in the production of OSB was to provide slip characteristics to the wood surfaces. The initial penetration of liquids in boards was through the voids between the wood particles (Maloney, 1993). From the results of this study, reducing wax content in the surface tended to give better TS. Reducing wax content in the core layer tended to result in better WA. These results agreed with Carll (1996) and Youngquist et al (1986) who stated that wax sizing decreased water absorption and dimension changes especially thickness swell, except water absorption due to the influence of void volume. One concern was that the inclusion of wax may reduce some of the strength properties below the minimum values of the appropriate specifications. Wax quantity of 1% or less had little or no effect on the strength properties of boards. Figure 4-3 showed the relationship between 24 hours edge TS and 24-hours one-inch inside TS. 24-hours one-inch inside TS had moderate positive correlation ($R^2 = 0.56$) to 24-hours edge TS. This result related to Gu et al (2004)'s finding. Figure 4-4 showed the relationship between 8 and 24-hours one-inch inside TS of 23/32" thick OSB. One-inch inside TS, edge TS and WA was related to water exposure time. Therefore, TS after 8-hours water exposure can be used to

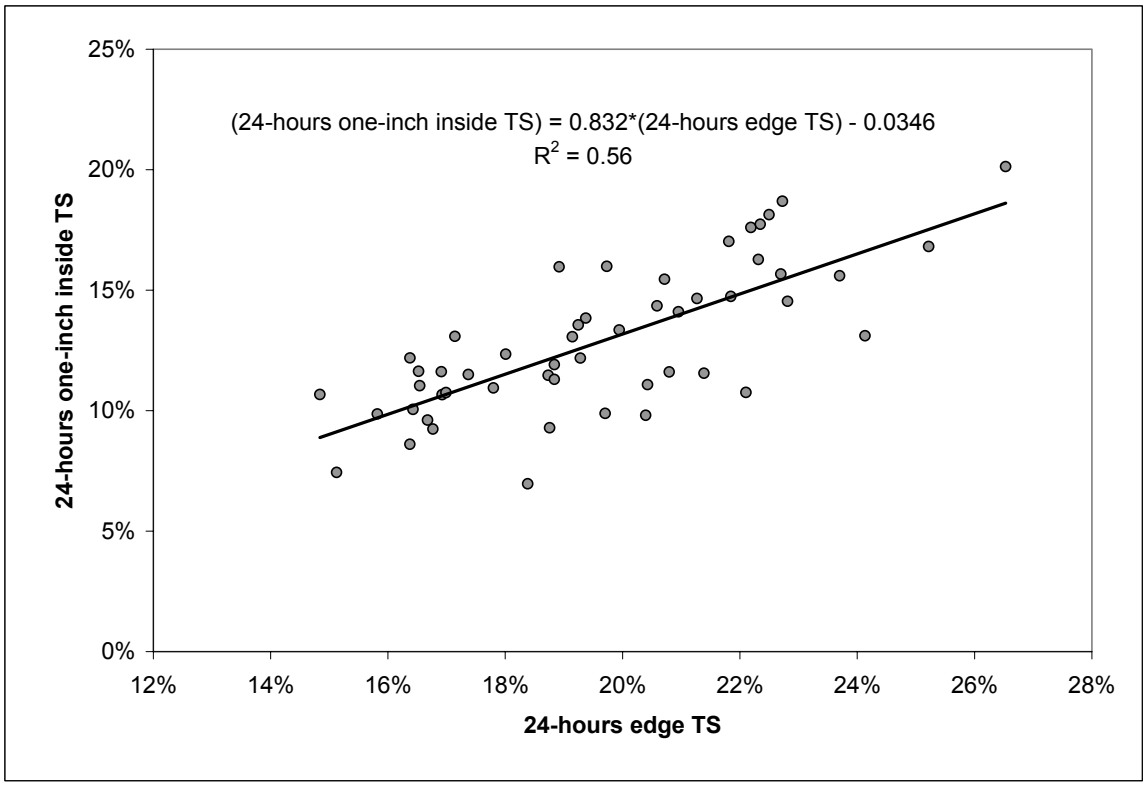

Figure 4-3. The relationship between 24-hours edge TS and 24-hours one-inch inside TS of 23/32" thick OSB.

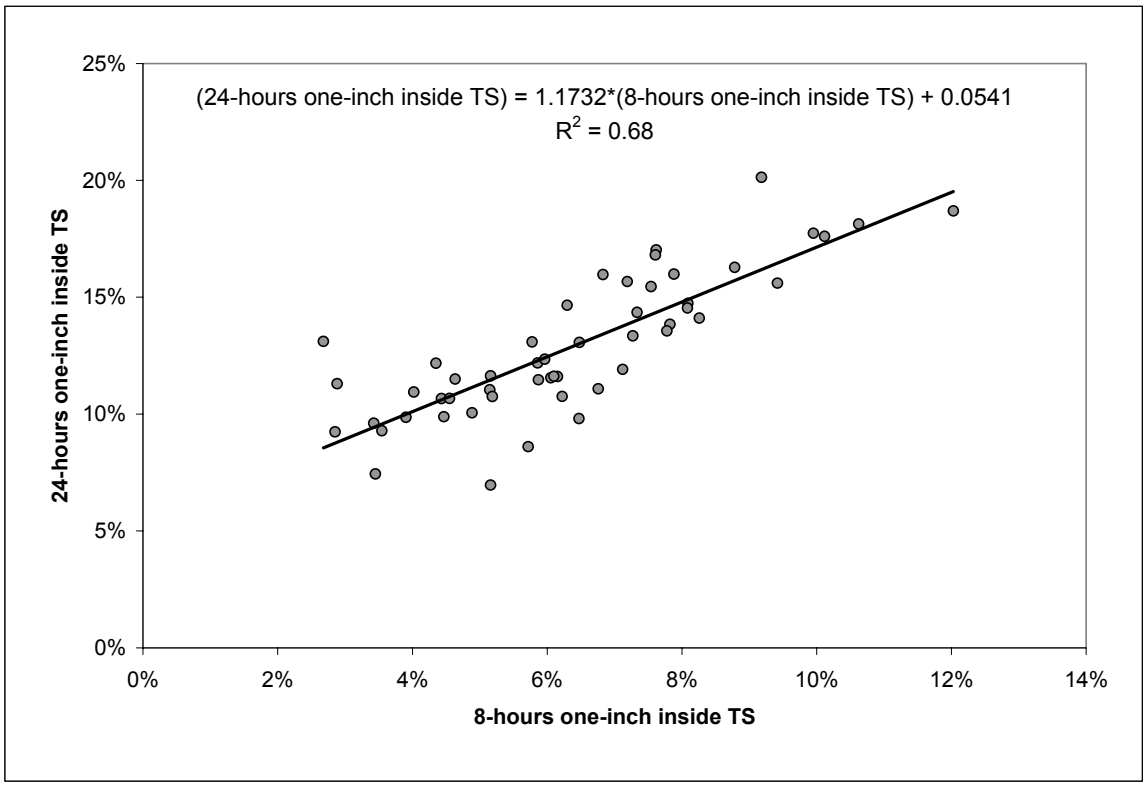

Figure 4-4. The relationship between 8-hours and 24-hours one-inch inside TS of 23/32" thick OSB.

predict TS after 24-hours water exposure. Using TS after 8-hours water soaked to predict the TS after 24-hours water soaked (R^2=0.68) was better than predicting TS after 96-hours water soaked (R^2=0.39).

4.3.4 Layer TS

4.3.4.1 Resin Influences

Table 4-7 showed actual and percentage of layer thickness swell of the face and core regions relative to the total thickness swell for OSB panels with different resin ratios of the OSB with PF as core resin. The shell ratio was 27.5-45-27.5%. After 8, 24 and 96-hours water exposure, actual layer TS of the top face was higher than the bottom face. The average top face, core and bottom face TS after the three water exposures for panel K-3.55/5.65 were 34-20-46% (8 hours), 34-23-23% (24 hours), 35-28-38% (96 hours). Core layer thickness swell increased with increased water exposure time. The face layer swells almost two times more than the core layer. The highest thickness swell occurred on layer #2 and #20 in the top and bottom surface respectively, which matched the vertical density profile. From the results, at the early stage of water exposure, about 80% of total thickness swell occurs in the face regions. Only 20% of total thickness swell occurred in the core region. The average top face, core and bottom face thickness swells after the three water exposures for panel O-5.40/3.40 were 35-22-43% (8 hours), 32-28-40% (24 hours), and 26-40-34% (96 hours). 78% of total thickness swell occurred in the face region of panel O-5.40/3.40 that had the highest resin content in face layer. The panel with higher resin loading in the face has lower percentage of thickness swell in the surface layer. At the same time, the panel with higher resin content in the core had a lower percentage of thickness swell in the core. In theory, the total edge thickness swell

Table 4-7. Percentage of layer thickness swell of face and core regions relative to the total thickness swell of 23/32" thick OSB with varied resin ratios.

Panel No.	Actual layer TS Shell ratio (27.5-45-27.5%)			Percentage layer TS Shell ratio (27.5-45-27.5%)		
	Top Face (Layers 1-4, part of layer 5)	Core (Part of layer 5, layers 6-15, part of layer 17)	Bottom Face (Part of layer 17, layers 18-23)	Top Face (Layers 1-4, part of layer 5)	Core (Part of layer 5, layers 6-15, part of layer 17)	Bottom Face (Part of layer 17, layers 18-23)
			8 hours water soaked			
L-4.05/5.05	27.9(5.1)	6.8(1.7)	25.4(5.2)	36.1(2.4)	20.6(3.5)	43.2(3.1)
N-4.95/3.95	29.9(8.4)	7.7(0.5)	23.6(2.3)	37.0(5.6)	23.8(3.5)	39.3(3.3)
M-4.50/4.50	26.3(4.6)	8.4(2.5)	23.8(9.2)	34.8(6.8)	25.9(4.3)	39.3(8.0)
K-3.55/5.65	26.3(4.3)	6.9(2.4)	28.8(6.3)	34.1(5.8)	19.7(3.9)	46.2(2.5)
O-5.40/3.40	23.5(3.2)	6.1(0.9)	20.5(4.1)	34.6(4.6)	22.5(3.3)	42.9(4.2)
			24 hours water soaked			
L-4.05/5.05	40.1(9.6)	10.8(2.2)	29.5(7.1)	36.2(2.5)	23.9(3.4)	39.9(2.5)
N-4.95/3.95	36.6(8.7)	13.3(1.6)	27.2(9.5)	34.6(4.3)	28.7(4.5)	36.7(2.5)
M-4.50/4.50	37.6(5.3)	11.1(2.8)	24.5(8.2)	34.5(6.5)	29.3(4.9)	36.2(6.1)
K-3.55/5.65	34.0(2.5)	10.2(3.2)	30.6(11.6)	34.3(5.6)	22.6(5.0)	43.1(2.4)
O-5.40/3.40	33.8(3.6)	12.8(2.1)	27.3(9.7)	31.6(3.6)	28.3(2.7)	40.2(3.1)
			96 hours water soaked			
L-4.05/5.05	47.2(3.1)	16.3(1.9)	36.5(4.6)	35.1(1.1)	28.3(2.3)	36.6(1.3)
N-4.95/3.95	50.1(6.7)	21.2(1.8)	40.6(4.9)	32.1(3.8)	33.6(2.4)	34.3(2.1)
M-4.50/4.50	46.0(8.2)	19.0(2.0)	33.9(6.9)	32.2(5.4)	34.7(4.3)	33.2(6.7)
K-3.55/5.65	50.5(3.1)	17.6(2.6)	44.6(6.0)	34.5(4.5)	27.8(2.3)	37.7(2.3)
O-5.40/3.40	41.3(4.6)	24.4(2.8)	38.1(2.6)	26.4(2.7)	39.6(3.5)	34.0(3.6)

was equal to the sum of the thickness swell of the individual layers. Panel O-5.40/3.40 had lower edge TS than panel K-3.55/5.65. Therefore, it can be concluded that the face layer especially top surface had more influence on total thickness swell than the core layer. Although the percentage of thickness swell of the bottom layer was higher than the core layer, the actual layer thickness swell in the top face was higher than the bottom face because the bottom face contains more fine particles, which could make it denser. This was why there was a high bottom face density for most of the panels. Figure 4-5 showed percentage of layer thickness swell of face and core regions relative to total thickness swell of panel M-4.50/4.50. Figure 4-6 showed actual layer thickness swell of face and core regions relative to total thickness swell of panel M-4.50/4.50. Table 4-8 showed correlation between face and core resin content to top face, core and bottom face thickness swell of 23/32" thick OSB with varied resin ratios of OSB with PF as core resin. From the results, there was a slight positive correlation between face resin and face-to-core resin ratio to core thickness swell after 8-hours water exposure. The core resin content has a slight negative relationship to core thickness swell after 8-hours water exposure. After 24-hours water exposure, the face resin content and face-to-core resin ratio were moderately positively related to core thickness swell and slightly negatively related to bottom face thickness swell. The core resin content had a moderate negative relationship to core thickness swell and a slight positive relationship to bottom thickness swell. After 96-hours water exposure, there was a high correlation between face resin content, core resin content and face-to-core resin ratio to core TS, a moderate correlation to top TS and a slight correlation to bottom TS. Figure 4.7 showed the relationship between resin ratios and 96-hours core TS of 23/32" thick OSB. We can predict the

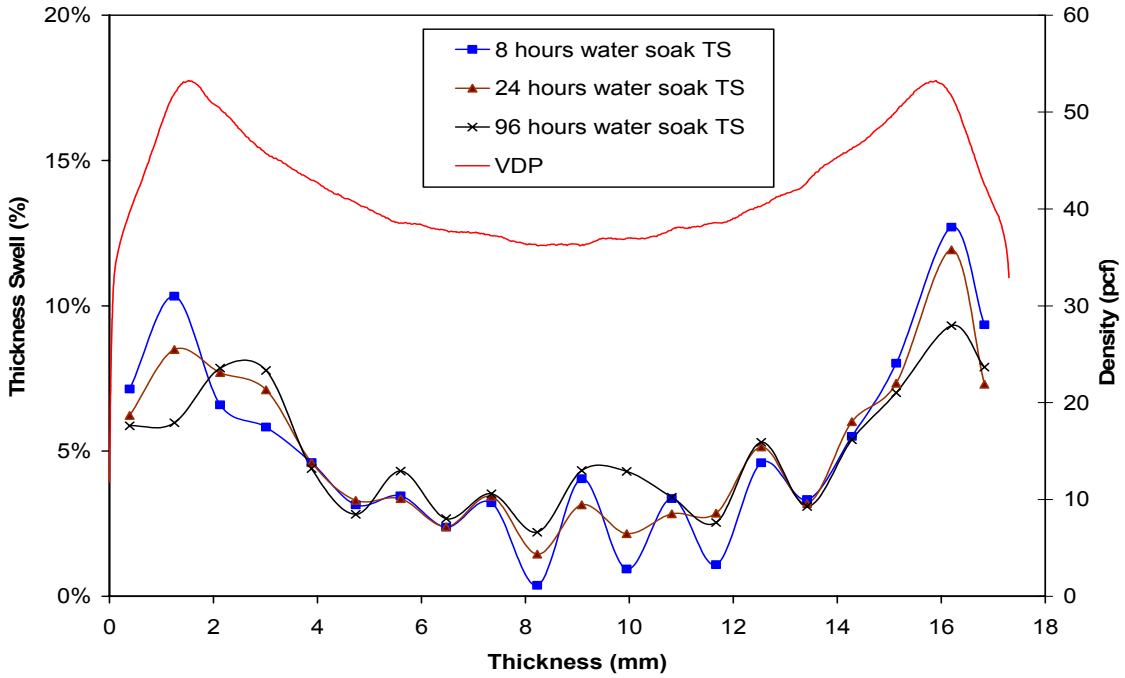

Figure 4-5. Percentage of layer thickness swell of 23/32" thick OSB with 4.5% PF resin content at face and core regions.

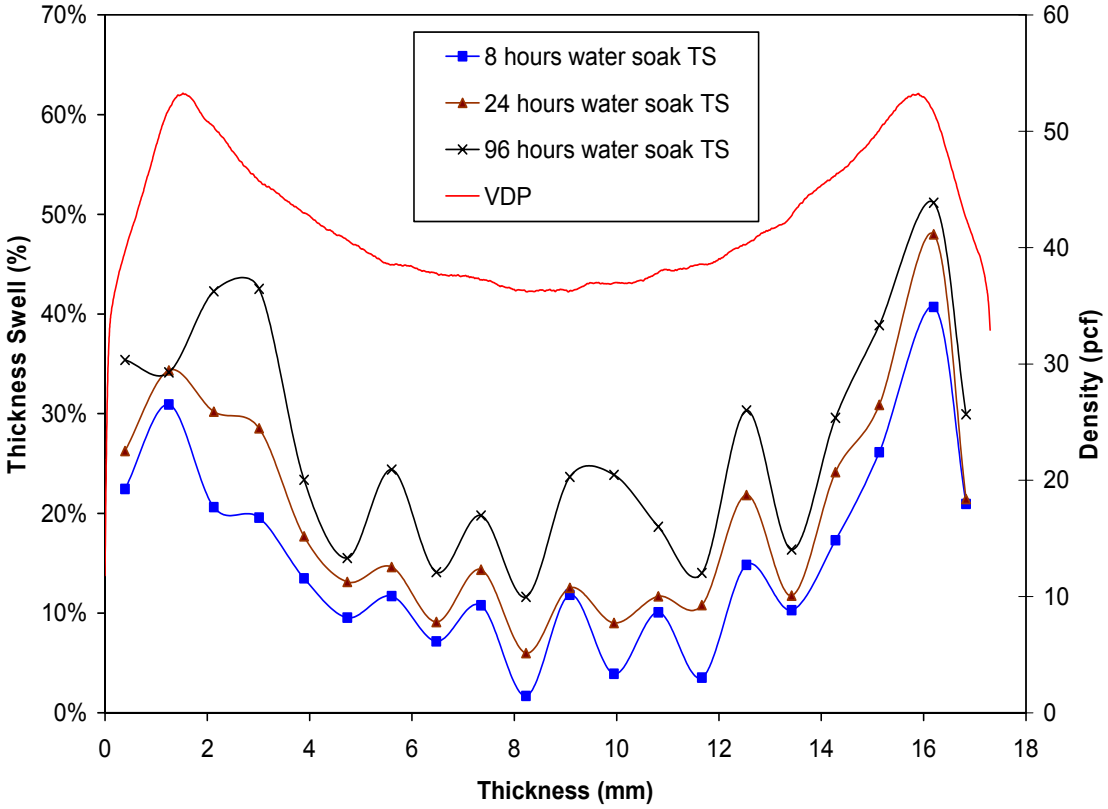

Figure 4-6. Actual layer thickness swell of 23/32" thick OSB with 4.5% PF resin content at face and core regions.

Table 4-8. Correlation between face and core resin content to top face, core and bottom face thickness swell of 23/32" thick OSB with varied resin ratios.

	8 hours water soak			24 hours water soak			96 hours water soak		
	Top	Core	Bottom	Top	Core	Bottom	Top	Core	Bottom
Face resin	0.0600	0.3545	-0.3294	-0.2171	0.5232	-0.3260	-0.5922	0.8071	-0.3749
Core resin	-0.0593	-0.3542	0.3285	0.2182	-0.5231	0.3246	0.5932	-0.8077	0.3744
Face-to-Core ratio	0.0255	0.3195	-0.2682	-0.2671	0.4974	-0.2413	-0.6397	0.8241	-0.3391

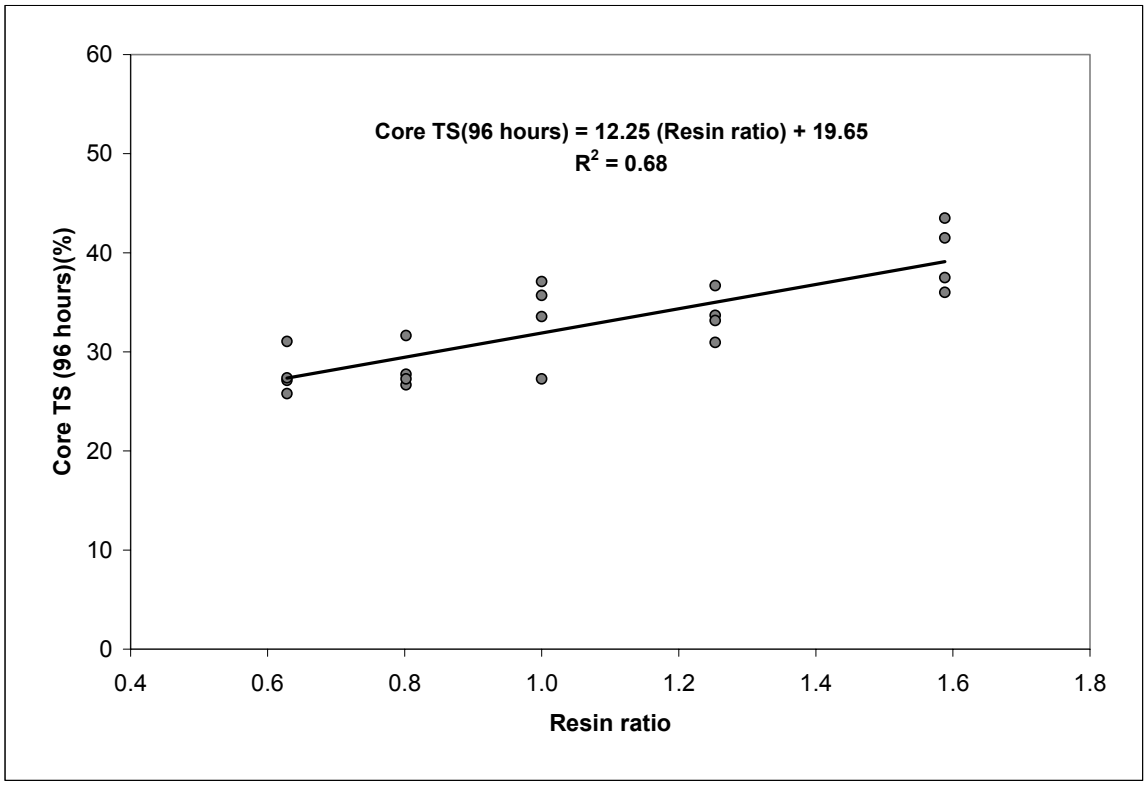

Figure 4-7. Relationship between resin ratio and core TS of 23/32" thick OSB after 96-hours water exposure.

core TS after 96-hours water exposure by the face-to-core resin ratio.

4.3.4.2 Wax Influences

Table 4-9 showed the face and core region contributions to the total thickness swell for OSB with different wax ratios of the OSB with PF as core resin. The shell ratio was 27.5-55.0-27.5%. The average top face, core and bottom face thickness swells at the three water exposure times for panel S-1.95/0.95 are 33-26-41% (8 hours), 33-29-38% (24 hours), and 31-34-35% (96 hours). From the results, about 74% of total thickness swell occurred in the face regions and only 26% of total thickness swell occurred in the core region after 8 hours water exposure. Panel S-1.95/0.95 had the highest wax content in the surface. The average top face, core and bottom face thickness swells at the three water exposure times for panel P-1.05/2.05 are 31-25-45% (8 hours), 31-31-38% (24 hours) and 29-37-34% (96 hours). 76% of total thickness swell occurred in the face region of panel P-1.05/2.05 that had the highest wax content in core layer. From the results, the panel with higher wax loading in the face or higher wax loading in the core layer did not make a difference in the percentage of TS in the face and core layers. Table 4-10 showed the correlation between face and core wax content to top face, core and bottom face thickness swell. From the results, wax content at the face layer had a slight positive relationship to the top face TS after 24 and 96-hours water exposure. Wax content at the core layer had a slight negative correlation to core TS after 8-hours water exposure. Face-to-core wax ratio had a slight positive correlation to core TS after 8-hours water exposure. Table 4-11 showed the face and core region contributions to the total thickness swell for OSB with different wax content of the OSB with PF as core resin.

Table 4-9. Percentage of layer thickness swell of face and core regions relative to the total thickness swell of 23/32" thick OSB with varied wax ratios.

Panel No.	Actual layer TS Shell ratio (27.5-45-27.5%)			Percentage layer TS Shell ratio (27.5-45-27.5%)		
	Top Face (Layers 1-4, part of layer 5)	Core (Part of layer 5, layers 6-15, part of layer 17)	Bottom Face (Part of layer 17, layers 18-23)	Top Face (Layers 1-4, part of layer 5)	Core (Part of layer 5, layers 6-15, part of layer 17)	Bottom Face (Part of layer 17, layers 18-23)
			8 hours water soaked			
M-1.50/1.50	26.3(4.6)	8.4(2.5)	23.8(9.2)	34.8(7.6)	25.9(2.0)	39.3(6.6)
R-1.68/1.28	28.1(6.1)	9.5(1.3)	26.6(7.3)	33.5(7.7)	26.2(4.4)	40.3(8.3)
Q-1.32/1.72	24.4(5.6)	9.9(3.7)	27.9(5.0)	29.7(4.8)	27.2(5.0)	43.2(3.9)
P-1.05/2.05	23.7(4.5)	8.1(2.0)	25.8(2.3)	30.8(7.1)	24.5(4.8)	44.7(4.3)
S-1.95/0.95	25.9(6.7)	8.2(1.0)	23.7(5.3)	33.1(5.4)	25.6(3.1)	41.3(7.8)
			24 hours water soaked			
M-1.50/1.50	35.6(4.3)	12.4(3.0)	24.5(8.1)	34.5(7.3)	29.3(2.6)	36.2(5.9)
R-1.68/1.28	35.1(9.9)	15.8(2.0)	29.4(7.3)	32.2(5.6)	30.7(5.4)	37.2(4.2)
Q-1.32/1.72	35.5(1.9)	15.5(3.2)	27.7(8.0)	31.8(5.6)	31.8(3.2)	36.5(2.5)
P-1.05/2.05	35.1(4.2)	13.6(0.6)	27.6(6.9)	31.1(3.5)	30.7(2.0)	38.2(2.9)
S-1.95/0.95	35.1(6.5)	13.4(1.4)	25.3(11.2)	32.6(5.7)	29.4(2.7)	38.0(6.7)
			96 hours water soaked			
M-1.50/1.50	43.7(7.9)	19.5(1.3)	34.4(7.5)	32.2(5.6)	34.7(2.1)	33.2(6.8)
R-1.68/1.28	42.6(7.2)	19.8(2.6)	35.1(5.3)	31.8(5.0)	34.9(6.3)	33.3(4.8)
Q-1.32/1.72	40.6(7.0)	19.9(1.8)	34.2(2.3)	31.4(5.1)	35.1(3.7)	33.5(2.0)
P-1.05/2.05	39.3(2.0)	19.9(1.3)	33.8(3.6)	29.2(2.3)	36.7(1.5)	34.2(2.6)
S-1.95/0.95	41.8(7.8)	18.5(2.1)	34.2(5.8)	31.4(2.9)	34.0(1.9)	34.6(4.4)

Table 4-10. Correlation between face and core wax content to top face, core and bottom face thickness swell of 23/32" thick OSB with varied wax ratios.

	8 hours water soak			24 hours water soak			96 hours water soak		
	Top	Core	Bottom	Top	Core	Bottom	Top	Core	Bottom
Face wax	0.1950	0.0617	-0.2268	0.3854	-0.3610	-0.1758	0.3483	-0.2081	-0.1491
Core wax	0.3017	-0.3916	-0.1000	0.1391	0.0640	-0.1854	0.1023	0.1432	-0.1752
Face-to-Core ratio	-0.1664	0.3674	-0.0229	-0.0101	-0.0970	0.0714	0.0315	-0.1421	0.0658

Table 4-11. Percentage of layer thickness swell of face and core regions relative to the total thickness swell of 23/32" thick OSB with varied wax contents.

Panel No.	Actual layer TS Shell ratio (27.5-45-27.5%)			Percentage layer TS Shell ratio (27.5-45-27.5%)		
	Top Face (Layers 1-4, part of layer 5)	Core (Part of layer 5, layers 6-15, part of layer 17)	Bottom Face (Part of layer 17, layers 18-23)	Top Face (Layers 1-4, part of layer 5)	Core (Part of layer 5, layers 6-15, part of layer 17)	Bottom Face (Part of layer 17, layers 18-23)
			8 hours water soaked			
M-1.50/1.50	26.3(4.6)	8.4(2.5)	23.8(9.2)	34.8(7.6)	25.9(2.0)	39.3(6.6)
T-1.50/0.50	26.6(2.3)	11.5(1.2)	31.4(6.4)	27.9(3.7)	29.3(2.4)	42.8(5.8)
U-1.50/1.00	29.4(7.5)	10.5(1.1)	34.0(3.7)	28.5(4.7)	26.6(3.1)	45.0(3.6)
V-0.50/1.50	25.1(6.1)	10.3(2.3)	31.1(2.5)	26.4(1.6)	27.2(4.5)	46.4(5.4)
W-1.00/1.50	28.8(3.0)	9.0(0.8)	27.1(4.6)	33.7(4.9)	25.7(0.8)	40.6(5.3)
			24 hours water soaked			
M-1.50/1.50	35.6(4.3)	12.4(3.0)	24.5(8.1)	34.5(7.3)	29.3(2.6)	36.2(5.9)
T-1.50/0.50	40.1(8.2)	17.7(2.9)	37.9(12.0)	29.0(3.2)	30.7(2.9)	40.3(4.7)
U-1.50/1.00	41.0(7.5)	14.4(0.8)	33.5(12.3)	30.5(3.5)	28.4(3.2)	41.0(3.2)
V-0.50/1.50	26.8(5.3)	13.9(1.7)	29.3(10.7)	25.2(2.4)	32.5(4.6)	42.3(4.0)
W-1.00/1.50	38.5(8.6)	13.9(1.3)	28.6(11.0)	33.0(4.7)	30.1(2.0)	36.9(6.2)
			96 hours water soaked			
M-1.50/1.50	43.7(7.9)	19.5(1.3)	34.4(7.5)	32.2(5.6)	34.7(2.1)	33.2(6.8)
T-1.50/0.50	45.5(9.1)	21.3(2.2)	45.5(10.4)	28.7(2.7)	33.7(3.0)	37.7(4.3)
U-1.50/1.00	46.1(7.2)	20.7(1.9)	47.3(5.5)	28.5(3.8)	32.8(3.3)	38.7(3.8)
V-0.50/1.50	35.7(4.0)	19.2(0.8)	37.4(1.8)	26.2(1.9)	35.7(2.4)	38.2(3.1)
W-1.00/1.50	40.6(3.6)	17.9(3.6)	38.9(4.7)	30.0(1.5)	32.7(3.9)	37.3(3.7)

4.4 Conclusion

This study found that resin and wax ratio influenced IB value seemed particularly strong on the core layer. IB value was improved as the resin ratio decreased. However, the IB was also improved as the wax ratio increased. The effect of resin ratio on MOR, MOE did not have evidence to show the improvement. The MOR and MOE were improved as the wax ratio decreased. One-inch inside TS, edge TS and WA decreased as resin ratio increased. However, one-inch inside TS, edge TS and WA decreased as wax ratio decreased. Face TS seemed more influence on total TS than core TS. The optimization of resin and wax ratio is necessary to improve the OSB properties in both mechanical properties and dimensional stability.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The optimization of resin and wax ratio is necessary to improve mechanical properties and dimensional stability of laboratory made OSB. Face and core variables affected laboratory made OSB. For 7/16" thick OSB, the MOR and MOE of laboratory made OSB panels were improved as the resin ratio increased in OSB with PF as core resin when tested parallel to face alignment and OSB with MDI as core resin when tested both parallel and perpendicular to face alignment. Resin and wax ratio influenced IB value seemed particularly strong on the core layer. Because IB was more sensitive resin distribution and resin procure, resin ratio had slightly affected IB. Increased wax ratio can improve MOR, MOE and IB in OSB with PF as core resin. However, the MOR, MOE and IB were improved as the wax ratio decreased in OSB with MDI as core resin. One-inch inside TS and edge TS decreased as resin ratio increased in the OSB. However the increase of wax ratio can decrease one-inch inside TS and edge TS. For 23/32" thick OSB, IB was improved as the resin ratio decreased and wax ratio decreased. The MOR and MOE were improved as wax ratio decreased but resin ratio had slightly affected MOR and MOE. One-inch inside TS, edge TS and WA decreased as resin ratio increased and wax ratio decreased. Resin ratio and wax ratio affected face and core TS. Higher resin and wax ratio can decrease TS.

5.2 Recommendations

A number of recommendations and implications emanated from this research, the resin ratio influenced on MOR and MOE especially in parallel direction. Composite

materials can be fabricated to meet the standard requirement. This study was to investigate the effect of wax and resin ratio on OSB properties. To improve the OSB properties the raw material was added to the fabricating process which increase the cost of products. The excellent OSB properties were desirable. Therefore the optimization of mat parameter should be accomplished in the future research. Nondestructive testing is new method for monitoring and investigating the OSB properties in process.

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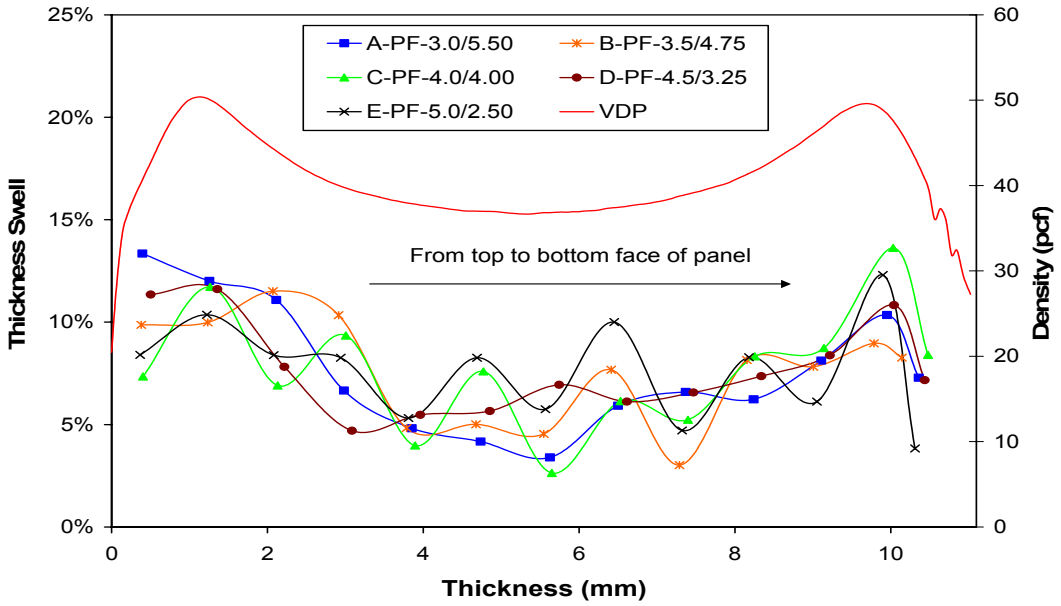
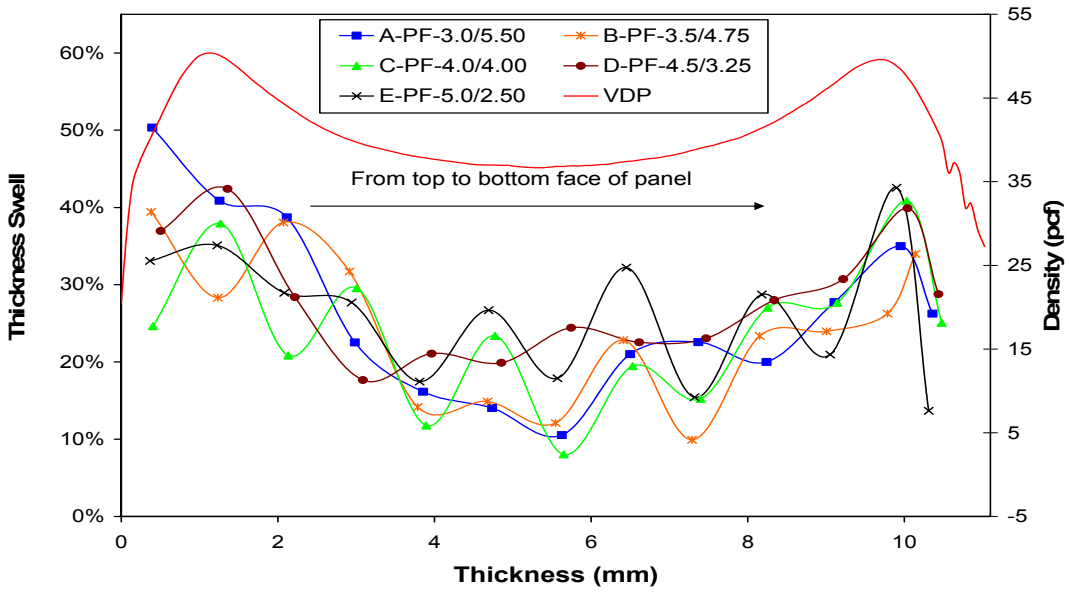
APPENDICES

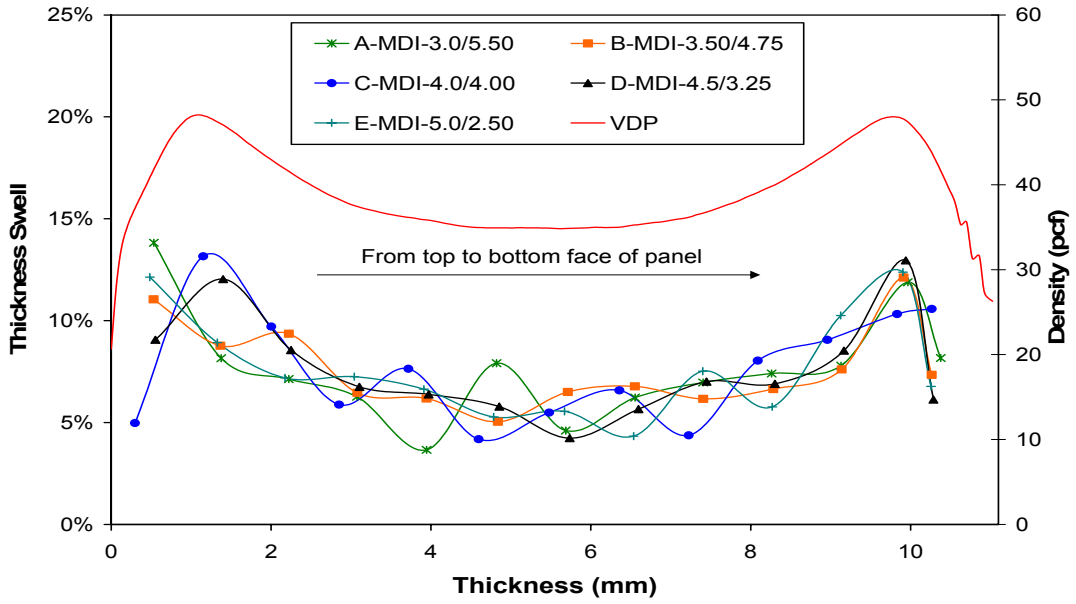
Appendix A. Actual layer thickness swell on individual layer of 7/16" thick OSB varied PF resin ratios after 24-hours of water exposure time.



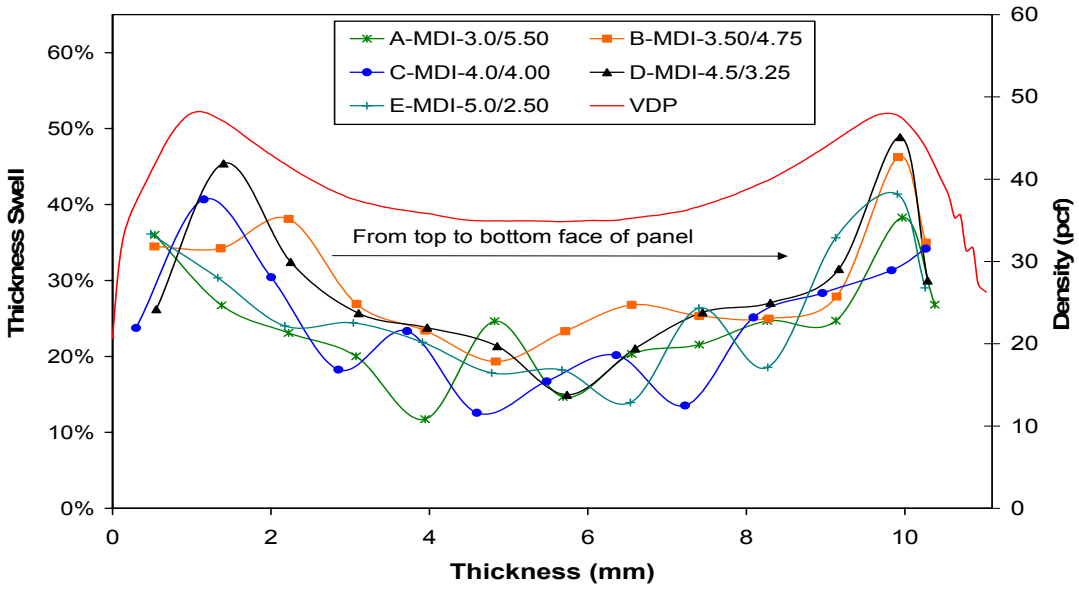
Appendix B. Percentage of layer thickness swell on individual layer of 7/16" thick OSB varied PF resin ratios after 24-hours of water exposure time.



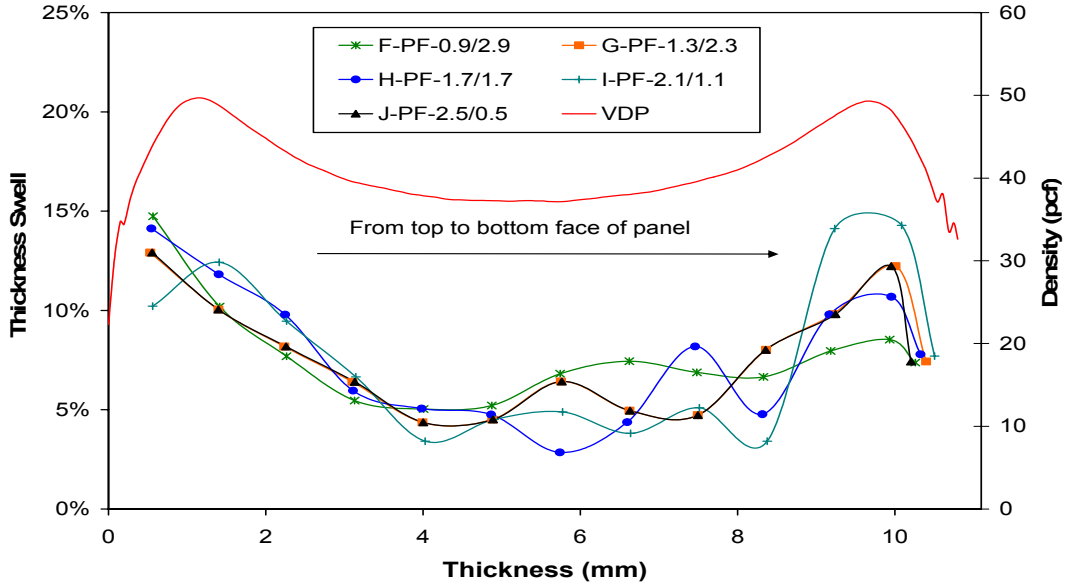
Appendix C. Actual layer thickness swell on individual layer of 7/16" thick OSB varied MDI resin ratios after 24-hours of water exposure time.



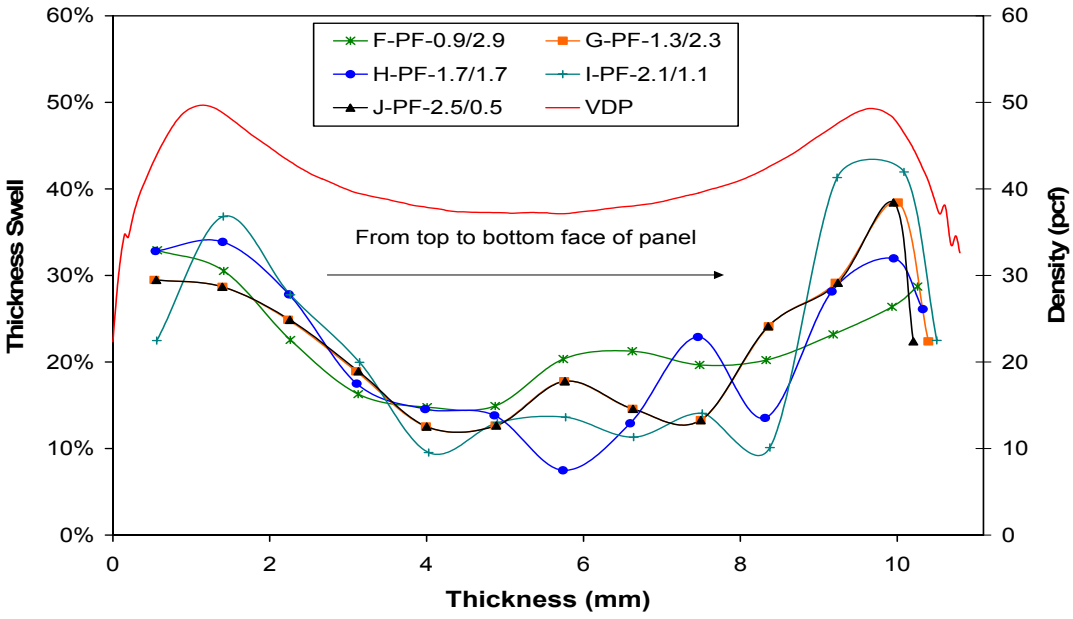
Appendix D. Percentage of thickness swell on individual layer of 7/16" thick OSB varied MDI resin ratios after 24-hours of water exposure time.



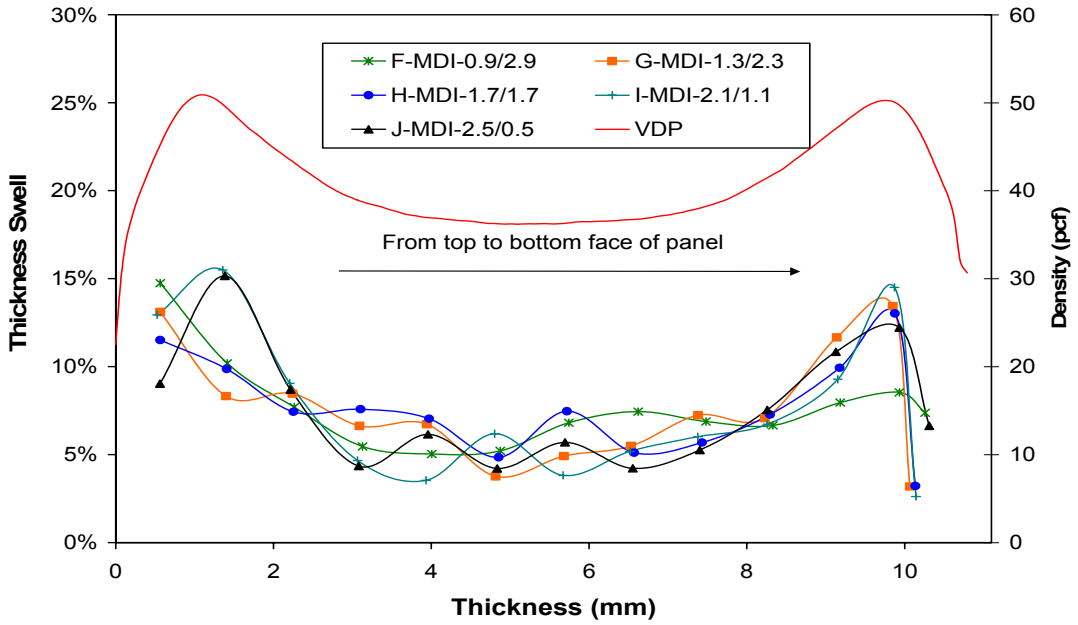
Appendix E. Actual layer thickness swell on individual layer of 7/16" thick OSB varied wax ratios in PF as core resin OSB after 24-hours of water exposure time.



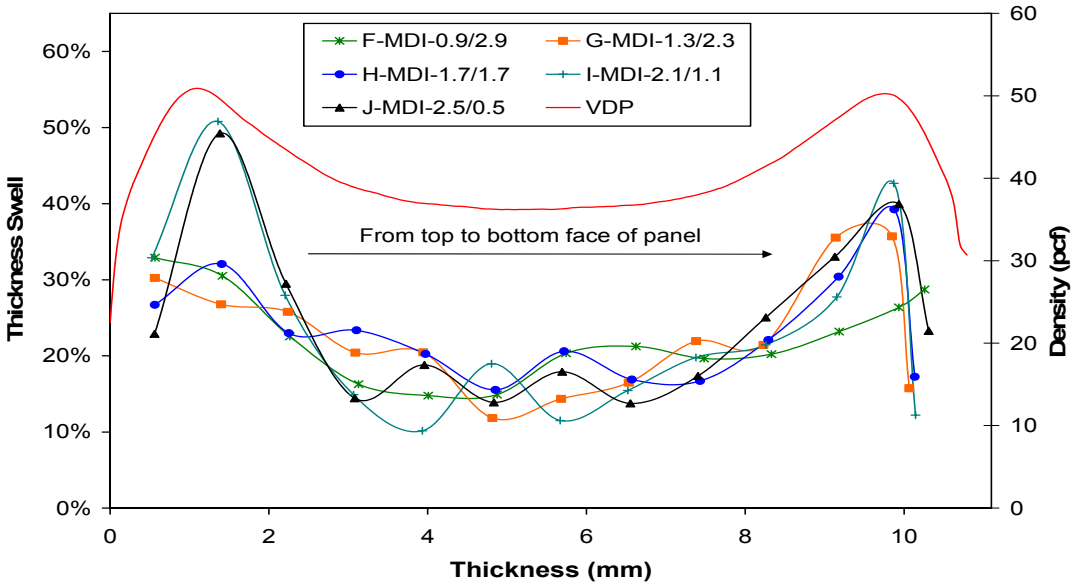
Appendix F. Percentage of layer thickness swell on individual layer of 7/16" thick OSB varied wax ratios in PF as core resin OSB after 24-hours of water exposure time.



Appendix G. Actual layer thickness swell on individual layer of 7/16" thick OSB varied wax ratios in MDI as core resin OSB after 24-hours of water exposure time.



Appendix H. Percentage of thickness swell on individual layer of 7/16" thick OSB varied wax ratios in MDI as core resin OSB after 24-hours of water exposure time.



VITA

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