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Effect of Resin Application Sequence, Content, and Powder/Liquid Combination Ratio on OSB Performance

by

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Abstract

Powder and liquid phenol-formaldehyde (PF) combination binder system has been commonly used in North America for oriented strand board (OSB) manufacturing. This binder system has shown its suitability for improving resin efficiency and bond quality as compared with either powder PF (PPF) or liquid PF (LPF) resin. This study was conducted to investigate the effect of resin application sequence (LPF-PPF-LPF, LPF-PPF, PPF-LPF), resin content (3.0%, 5.5%, 8.0%), and PPF/LPF combination ratio (50:50, 65:35, 80:20) on strand board performance. Board properties evaluated include internal bond (IB), thickness swelling (TS), water absorption (WA), dry and wet modulus of rupture (MOR), dry modulus of elasticity (MOE), edgewise shear, and compression shear strength. In addition, a non-destructive test method (TROBEND) developed at Forintek was also used to measure the modulus of elasticity (MOE) and shear modulus of elasticity (G).

Response Surface Methodology (RSM) was used in the experiment design. Significant response surface models were established for individual panel properties, including the linear model for IB, dry MOR, dry MOE, and compression shear, as well as the quadric model for TS, WA, and wet MOR, and 2FI (two factor interaction) for edgewise shear. ANOVA for response surface model indicated that the resin content was a significant model term for IB, TS, dry MOR and MOE, wet MOR, and compression shear properties. An increase in resin content improved these board properties. Powder/liquid ratio was a significant model term for TS, WA, and wet MOR. Resin application sequence was not a significant model term for any panel property, but its interaction with resin content was a significant model term for edgewise shear property.

In most cases, the interactions between experimental variables were not significant model terms for predicting panel properties, but they still revealed some trends. Regarding Sequence 3 (PPF-LPF), 50:50 PPF/LPF ratio (lower level) resulted in higher IB, dry MOR, and compression shear, while 80:20 PPF/LPF (higher level) yielded lower WA and higher dry MOE. For Sequence 2 (LPF-PPF), 65:35 PPF/LPF ratio (middle level) favoured TS, while 50:50 PPF/LPF ratio (lower level) favoured wet MOR. Sequence 1 (LPF-PPF-LPF) combined with 50:50 PPF/LPF ratio (lower level) also gave lower WA values. In general, an increase in resin content improved the board properties with the above combinations. In addition, Sequence 3 (PPF-LPF), with 3.0% resin (lower level), yielded higher edgewise shear strength regardless of resin application sequence.

An attempt was made to correlate the panel mechanical properties measured using both destructive and non-destructive test methods. The strongest correlation was observed between IB and compression shear (R^2=0.70), followed by TORBEND G with modulus of elasticity (TORBEND MOE) (R^2=0.40), and TORBEND G with compression shear (R^2=0.28) and with IB (R^2=0.26). However, no correlation seemed to exist between MOE (static bending) and TROBEND MOE.

An image analysis indicated that an increase in resin content significantly increased resin coverage on strand surface. At each resin content (3.0%, 5.5%, and 8.0%), a decrease in PPF/LPF ratio in Sequence 1 (LPF-PPF-LPF) or an increase PPF/LPF ratio in sequence 3 (PPF-LPF) seemed to result in higher resin coverage. Resin coverage seemed to correlate to TS (R^2=0.45), IB (R^2=0.42), compression shear (R^2=0.39), TORBEND G (R^2=0.39), dry MOR (R^2=0.25), wet MOR (R^2=0.25), and dry MOE (R^2=0.18). However, resin coverage did not seem to correlate to WA, TORBEND MOE, or edgewise shear properties.

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1 Objectives

To determine the effect of the resin application sequence of liquid and powder PF resin combination binder systems on OSB performance.

2 Introduction

At the present time, a liquid and powder combination binder system is commonly used in North America in oriented strand board (OSB) production. The powder binder in the combination binder system is usually phenol-formaldehyde (PF), while the liquid binder could be either PF or methylene diphenyl diisocyanate (MDI) resin. The combination binder system has shown a unique advantage in resin efficiency, i.e. maximizing OSB panel performance with minimum resin application levels. Such a binder system has also demonstrated its suitability for making special engineered wood products, such as web stocks for I-beams, in which a higher quantity of resin is required in order to achieve higher internal bond strength and shear strength in OSB panels. So far, some studies on liquid/powder combination binder systems for flakeboard and OSB have been reported. These studies dealt mainly with liquid and powder combination ratios and resin application rate; however, limited information is available on resin system performance as influenced by resin application sequence in combination with resin content and powder-to-liquid ratio.

The current study is the continuation of the series of studies on improving adhesive application systems in OSB production. So far, two progress reports have been issued, entitled “Effect of Powder and Liquid PF Resin Combination Binder System on OSB Performance” and “Effect of MDI and Powder PF Combination Binder System on OSB Performance.” The purpose of this current study was to examine how resin application sequence (i.e. a powder resin being applied before or after a liquid one) influences combination resin distribution and bond quality.

3 Background

Oriented strand board (OSB) mills increasingly resort to combinations of liquid PF (LPF) and powder PF (PPF) or MDI and PPF resins to improve resin efficiency, especially when they process wood species other than aspen. Resin efficiency, measured in terms of resin distribution, retention, coverage, and bond quality, can be improved by optimizing the powder resin application and adjusting the powder/liquid resin combination ratio depending on final application requirements. The use of a combination binder system allows for maximum panel performance with minimum resin application rates. It also allows for the use of greater quantities of resin that are needed to bond special engineered wood products (EWP), such as webs for I-beams, which normally require higher internal bond strength and shear strength. For these products, neither powder nor liquid PF resin alone could meet the requirements because of the limitations of powder resin retention on strand surfaces and the longer pressing cycles used for panels with a higher mat moisture content introduced by the liquid resin.

In North America, phenolic resins in either powder or liquid form have been used for OSB production. Both resin forms have advantages and disadvantages regarding resin efficiency. A comparison of powder and liquid phenolic resins indicates that the primary factors adversely affecting the efficiency of liquid resins are viscosity, resin molecular weights, and resin non-volatile percentage. These factors affect resin distribution, resin cure speed, mat moisture, drying capacities, and dryer and press emissions (Davis 1993). Other factors that may affect the efficiency of liquid phenolic resins include short storage life, high resin dosage, and high transportation costs (Go 1988). However, these factors can be eliminated by using powder phenolic resins. This is due to the current spray technology, which enables a powder resin manufacturer to change molecular weight, particle shape and size distribution, bulk density, formaldehyde content, and flowability (David 1993; Ellis 1996), and consequently makes it possible to influence panel properties (Ellis 1993a; Ellis 1993b; Ellis and Steiner 1990; Ellis and Steiner 1991). However, limitations in using powder resin involve the resin distribution and retention on strand surfaces, especially when high density wood species are used as a substitute for aspen or when a high resin content is required in order to improve bond quality (Wang et al. 1999; Wang and Wan 2001).

Hse et al. (1994) investigated the effect of resin type on the performance of flakeboards produced by steam-injection and conventional pressing. In that study, a combination system was obtained by applying the MDI resin before the LPF resin. With steam injection pressing, the authors found that using a small amount of MDI resin significantly improved the mechanical and physical properties of southern pine and white oak boards. However, no significant improvement in board properties was observed for combined MDI/LPF (15:85) resin with conventional platen pressing.

Miller and Rosthauser (2002) investigated the potential for using aqueous mixed PMDI/LPF to manufacture OSB and particleboard. Their study indicated that, compared with the use of liquid PF resin, the use of PMDI/LPF combination with bis (4-hydroxy) benzophenone oxime (blocking agent) improved particleboard quality. However, the use of mixed binder did not seem to improve OSB performance regardless of the type of blocking agent used.

Wang and Wan (2001) investigated the effect of different adhesive systems on the performance of OSB panels made with mixed wood species (60:20:20 aspen/white birch/yellow birch, 60:40 aspen/red maple, 50:50 southern yellow pine/sweet gum) at board densities ranging from 38 to 44 lb/ft^3 (608 to 704 kg/m^3). An overall comparison showed that at the same resin content (2.5%), a powder/liquid (60:40) combination system appeared to produce stronger panels than powder or liquid resin alone.

Recent studies on liquid/powder combination binder systems for OSB manufacturing were conducted by Wang and Wan (2002a, 2002b). In the study on PPF/LPF binder system, variables such as powder/liquid resin combination ratios (0:100, 25:75, 50:50, 75:25, 100:0) and resin contents (2.0%, 3.5%, 5.0%) were investigated (Wang and Wan 2002a). The study showed that an increase in resin content significantly improved resin coverage and panel performance. Powder/liquid combinations (between 25:75 and 75:25) improved resin efficiency with respect to internal bond strength and water resistance compared to powder or liquid resin alone. In the study on MDI/PPF binder system, Wang and Wan (2002b) evaluated the influence of processing variables such as liquid/powder combination ratio and mat moisture variation on OSB performance. It was found that OSB panels bonded with 75/25 and/or 50/50 MDI/PPF combinations were statistically comparable for all panel properties. MDI and MDI/PPF (50/50) binder systems were more tolerant to furnish MC variation compared to PPF resin.

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5 Materials and Methods

5.1 Resin Characterization

The liquid and powder PF resins used in this study were supplied by a resin manufacturer. All resins were received on September 26, 2002, and kept at 10^{o}C in a refrigerator until used for making panels on November 11, 2002. The powder resin was characterized for fusion diameter (AMTB204) and the liquid resin for viscosity and gel time at the time of use. A summary of resin characteristics is given in Table 1.

Table 1 Resin characterization

Resin	Moisture Content (%)	Fusion Diameter (mm) 0.5-g Resin	Solid Content (%)	Viscosity (cps @25^{o}C)	Gel Time (sec.@5g/ 120^{o}C)
Powder PF	6.0	29	N/A	N/A	N/A
Liquid PF	N/A	N/A	50	260	375

5.2 Strand Preparation

In this study, a mixed wood species was used, consisting of 60% aspen (*Populus tremuloides*) and 40% white birch (*Betula papyrifera*). Aspen strands with dimensions of approximately 4 in. long by 0.030 in. thick by random widths were received from a Forintek's member OSB mill. White birch strands with similar geometry were prepared at Forintek using a CAE waferizer with a 6 in. x 6 in. feeding slot. Aspen and white birch strands were dried separately at 65°C in a drum-dryer to about 1-2% of moisture content. Fines passing 3/8-in. diameter screen inside the dryer were rejected during the drying process. The strands of the two species were mixed proportionally at the time of blending.

5.3 Experimental Design

Three variables were selected in this study on the influence of resin application sequence on OSB panel performance, and each variable consisted of three levels as follows:

Resin content:	(1) 3.0% (solid basis)
	(2) 5.5% (solid basis)
	(3) 8.0% (solid basis)
Application sequence:	(1) LPF-PPF-LPF (liquid followed by powder and then liquid)
	(2) LPF-PPF (liquid followed by powder)
	(3) PPF-LPF (powder followed by liquid)
PPF/LPF ratio:	(1) 50:50 (wt/wt on a solid basis)
	(2) 65:35 (wt/wt on a solid basis)
	(3) 80:20 (wt/wt on a solid basis)

Response Surface Design (Design-Expert 6.0.5) was used for the experiment design. For this experiment with three factors and three levels per factor, Design Expert yielded a total of 17 runs in random order. In this typical design, Run 7 (Std 17) was eliminated to lower the number of panels to be made since this run was repeating four runs (5, 8, 10, 15) corresponding to Standard (Std) Order 16, 15, 13, and 14, respectively. It should be noted that for the same number of experimental factors, the run order could be different each time since Design-Expert randomizes the order, but the Standard Order remains the same. The design layout for this experiment is shown in Table 2. Among 15 runs, two replicate panels were made for Runs 5 and 10, four replicates for Run 16, and three replicates for the rest of the runs, giving a total of 48 panels for 16 runs.

Table 2 Design layout with response surface design (Box-Behnken)

Std	Run	Resin Content (%)	PPF/LPF Ratio	Application Sequence	Comments
11	1	5.5	50	3	Powder - Liquid (PPF-LPF)
10	2	5.5	80	1	Liquid - Powder - Liquid (LPF-PPF-LPF)
4	3	8.0	80	2	Liquid - Powder (LPF-PPF)
8	4	8.0	65	3	Powder - Liquid (PPF-LPF)
16	5	5.5	65	2	Liquid - Powder (LPF-PPF)
7	6	3.0	65	3	Powder - Liquid (PPF-LPF)
15	8	5.5	65	2	Liquid - Powder (LPF-PPF)
5	9	3.0	65	1	Liquid - Powder - Liquid (LPF-PPF-LPF)
13	10	5.5	65	2	Liquid - Powder (LPF-PPF)
3	11	3.0	80	2	Liquid - Powder (LPF-PPF)
9	12	5.5	50	1	Liquid - Powder - Liquid (LPF-PPF-LPF)
6	13	8.0	65	1	Liquid - Powder - Liquid (LPF-PPF-LPF)
1	14	3.0	50	2	Liquid - Powder (LPF-PPF)
14	15	5.5	65	2	Liquid - Powder (LPF-PPF)
2	16	8.0	50	2	Liquid - Powder (LPF-PPF)
12	17	5.5	80	3	Powder - Liquid (PPF-LPF)

5.4 Resin Application

In this study, all panels were made in a three-layer construction in terms of strand moisture content and slack wax content. Therefore, resins were applied to the face and core layer furnishes separately. For each blending of face or core furnish in a run, 8 kg of wood (dry basis) was loaded into the blender. A 2.0% (for face furnish) or 1.5% (for core furnish) slack wax based on OD wood weight was applied to the strands though a nozzle (spray set-up No.SU42) at an air pressure of 30 psi.

For the application sequence of LPF-PPF, the liquid resin was applied first through two nozzles (spray set-up No.SU22B). The air pressure for the liquid resin application was controlled at 80 psi and at a resin flow rate of 100-120 ml/min in order to achieve an optimum atomization for the given blender set-up. The nozzles for wax and liquid resin atomizing were both manufactured by the Spraying System Co. After liquid resin was applied, powder resin was applied to strands over a period of 1-2 min through a blower, followed by 1 or 2 min tumbling, to make a total of 3 min of dwell time for powder resin application in the powder/liquid combination. The blowing rate of powder varied with the amount of powder and was manually controlled at an air pressure of 80 psi.

For the application sequence of PPF-LPF, the powder resin was applied first, followed by the liquid resin using the same application conditions as for the LPF-PPF sequence. When the LPF-PPF-LPF sequence was used, the liquid resin was divided into two equal portions: half of the liquid resin was applied before the powder resin and the other half was applied after the powder application.

To minimize the variation of blending quality from batch to batch, the blender was thoroughly cleaned by vacuum after each blending to remove fines and powder resin attached to or deposited on the wall of blender. Actual resin application times and moisture contents after blending for face and core layers in each run are summarized in Table 3.

Table 3 Resin application times and mat moisture contents

Run	Blowing Time for Powder Resin (sec.)		Spraying Time for Liquid Resin (min-sec.)		Furnish Moisture Content after Blending (%)	
	Face layer	Core layer	Face layer	Core layer	Face layer	Core layer
1	120	116	N/A	4’50”	7.6	5.1
2	128	135	1’28”/1’22”	1’09”/1’24”	7.6	5.4
3	140	130	2’53”	3’03”	7.9	5.8
4	125	120	4’50”	N/A	8.4	5.5
5	110	100	3’22”	3’32”	8.2	5.2
6	117	116	N/A	2’18”	8.3	5.6
8	105	106	3’20”	3’25”	8.0	5.1
9	108	118	1’20”/1’12”	1’14”/1’22”	7.4	5.4
10	135	118	2’51”	3’13”	7.6	5.1
11	115	110	1’23”	1’29”	7.2	5.1
12	110	128	2’51”/2’53”	2’50”/2’55”	7.2	5.5
13	117	60	2’56”/2’46”	2’56”/2’40”	8.1	5.6
14	41	60	1’55”	2’15”	8.5	5.5
15	110	60	2’39”	3’06”	8.1	5.5
16	65	65	5’43”	5’40”	7.7	6.5
17	75	75	1’50”	2’31”	8.2	5.8

5.5 Image Analysis of Resin Coverage

Resin coverage on strand surfaces was determined by an image analysis system. After blending, a set of 25 resinated surface strands was randomly selected from each blend. The strands were heated for 45 minutes at 180^{o}C to cure the resin in an oven to darken resin spots. A 3-Charged-Coupled-Device (CCD) high-resolution digital colour camera was used to take pictures of each strand. Two pictures were taken on each side of the strand, which gave a total of 100 pictures per blend. The result of resin coverage (percentage) at each blending condition was expressed as an average.

5.6 Panel Preparation and Evaluation

A Dieffenbacher hot press (34 in. x 34 in.) equipped with a PressMan control system was used to press boards. The profiles of mat gas pressure and temperature at the centre of each board, measured by a probe, are presented in Appendix I. Mat thickness and pressure as a function of press time are also shown in the pressing diagram in Appendix I. A total of 48 panels were manufactured in this study by following the run order listed in Table 2. Detailed information on the panel preparation conditions is summarized in Table 4.

Table 4 General panel manufacturing parameters

Panel dimension	11.1 mm (7/16 in.) x 610 mm (24 in.) x 610 mm (24 in.)
Mass distribution (weight/weight)	25:50:25 (face/core/face)
Panel construction	Three layers in terms of mat MC and wax content
Wood species	60:40 (aspen/white birch)
Strand dimension	Aspen (4 in. x 0.030 in. x random wide) White birch (3 in. x 1 in. x 0.20-0.25 in.)
Supports	Screen at the bottom
Blender	5.6 ft (diameter) x 3.4 ft (depth)
Blending rotation speed	11 rpm
Nozzle/blower angle	-15^o (downward)
Air pressure for wax application	30 psi
Air pressure for liquid resin application	80 psi with a flow rate of 100-120 ml/min
Air pressure for blowing powder	80 psi
Total blending time for powder resin	3 min (including blowing and tumbling)
Total blending time for liquid resin	1.5 - 5.5 min depending on resin contents
Mat MC	7.2-8.5% for face layer; 5.1-6.5% for core layer
Slack wax content	2.0% for face furnish; 1.5% for core furnish
Resin type	Powder PF (PPF); liquid PF (LPF)
Resin content	(1) 3.0% (2) 5.5% (3) 8.0% (solids basis)
PPF/LPF weight ratio	(1) 50:50 (2) 65:35 (3) 80:20
Resin application sequence	(1) LPF-PPF-LPF; (2) LPF-PPF; (3) PPF-LPF
Target OD density	39 lb/ft^3 (624 kg/m^3)
Press temperature	220°C (steam)
Total press time	150 seconds (daylight to daylight)
Closing time:	30 sec.
Degas	40 sec.
Replicate	2-4

After pressing, all panels were kept in a conditioning room at 65% RH/20^{o}C for at least three weeks prior to sampling and testing. Panel properties such as internal bond (IB), dry and wet modulus of rupture (MOR), dry modulus of elasticity (MOE), 24-h thickness swelling (TS), and 24-h water absorption (WA) were measured according to CSA Standard O437.1-93; edgewise shear and compression shear strengths were measured according to ASTM D 1037.

Edgewise shear test (shear normal to the plane of the panel) is made on a specimen clamped between two pairs of steel load rails. Shear force in the specimen is introduced by loading the rails in compression as shown in Figure 1. Failure occurs across the panel in combination with diagonal tension and compression. The edgewise shear strength is calculated using the following formula:

$$fs = P/Ld$$

where:	*fs*	=	edgewise shear strength, psi (kPa)
	d	=	thickness of specimen, in. (mm)
	L	=	length of specimen, in. (mm)
	P	=	maximum compressive load, lb (kg)

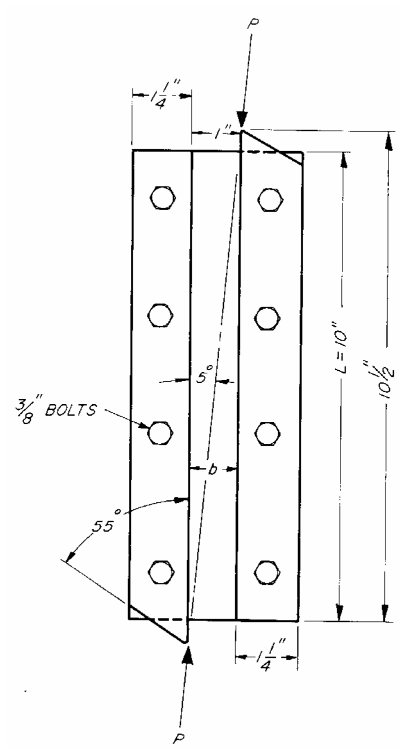


Figure 1 Diagram of edgewise shear test [Reproduced from <u>1997 Annual Book of ASTM Standards</u>, Volume 04.10, Figure 23, "Detail of Loading Rails Used with Edgewise Shear Specimen." p. 160]

Compression shear test is carried out without gluing or clamping, as shown in Figure 2. The compression shear strength determined by the test provides an indication of the bond quality of material subjected to shear deformation, thus it correlates to the tensile strength perpendicular to surface (internal bond) test. The compression shear strength is calculated using the following equation:

$$T = P\sqrt{2A}$$

where:	*T*	=	maximum-shear stress, psi (Pa)
	P	=	maximum load, lbf (N)
	A	=	product of length and width dimensions, in^2 (mm^2)

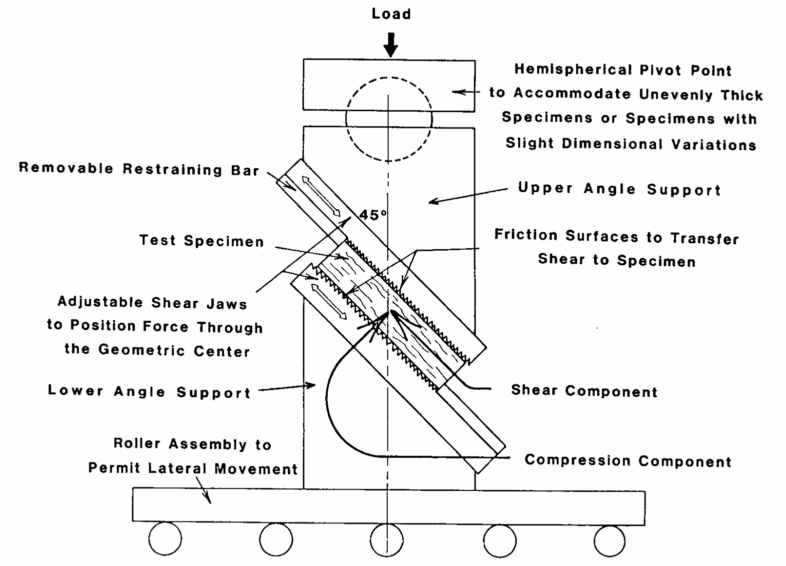


Figure 2 Diagram of compression shear test [Reproduced from 1997 Annual Book of ASTM Standards, Volume 04.10, Figure 29, "Principle of Compression-Shear Test." p. 163]

The bending and shear properties of panels were also evaluated using a torsion-bending vibration test method based on relationships between vibration characteristics and mechanical properties. This non-destructive test method was developed at Forintek and employs a mechanical device called TORBEND (Lau and Tardif 1996). TORBEND can simultaneously measure the natural bending frequency (f_1) and torsion frequency (f_2) of a panel supported as a cantilever beam, as shown in Figure 3. The test is normally made in both perpendicular and parallel directions of the panel.

In combination with some panel physical parameters, such as board span, thickness, and density, frequencies in the bending (f_1) and torsional (f_2) modes of vibration can be related to a panel's modulus of elasticity (E or MOE) and shear modulus of elasticity (G), respectively. With panel thickness (h), two important properties for determining the qualification of panels for I-beam application can be calculated as follows:

Bending stiffness (B_b) = $E \cdot h^3/12$

Shear through-thickness rigidity (B_v) = $G \cdot h$

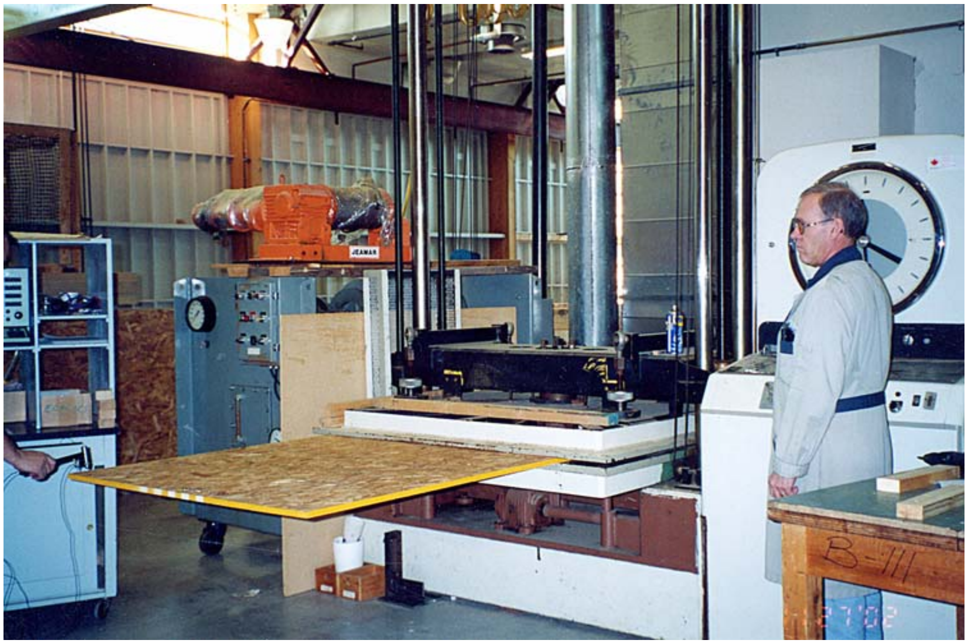


Figure 3 Torsion-bending vibration (TORBEND) testing machine for measuring modulus of elasticity and shear modulus of elasticity of OSB panel [Note: the panel in demonstration was not one from the current study]

6 Results and Discussion

6.1 Mechanical and Physical Properties

Board density and moisture content (MC) are shown in Table 5 and the detailed information on MC is given in Appendix II. The average board density after conditioning to 20°C/65% RH was 668 kg/m^3 with a range of 654 to 691 kg/m^3. The average OD board density was 615 kg/m^3, ranging from 602 to 637 kg/m^3, which was slightly lower than the target OD board density of 624 kg/m^3. Coefficients of variation were 1.47%, 1.50%, and 1.58% for board density (after conditioning), OD board density, and board MC, respectively. The coefficients of variation were thought to be at their normal levels.

Board mechanical and other physical properties are also shown in Table 5 and Table 6, and the raw data is given in Appendices III-IX. Perturbation plots were used to describe how panel properties changed as each main variable (resin content, powder/liquid ratio, or resin application sequence) moves from the chosen reference point, with all other variables held constant at the reference value. As shown in Figures 4-11, the perturbation plots provide silhouette views of the response surface for each panel property. The reference value chosen for the plots was the middle level of each variable (coded 0). The lower and higher reference values were coded (-1) and (+1) for lower and higher levels of each variable. From Figures 4-11, it was found that the resin application sequence and powder/liquid resin combination ratio seemed to have relatively little effect on overall panel properties compared with resin content. The relationship and interaction between resin application sequence and powder/liquid ratio at different resin contents are shown in Figures 12-19.

6.1.1 Internal Bond (IB)

Figure 12 illustrates that an increase in resin content from 3.0 to 8.0% improved IB strength regardless of resin application sequence (LPF-PPF-LPF, LPF-PPF, PPF-LPF) and PPF/LPF Ratio. There was a slight interaction between resin application sequence and PPF/LPF ratio at each resin content. Higher IB panels seemed to result from Sequence 3 (PPF-LPF) and the lower PPF/LPF ratio (50:50). These observations indicate that higher resin content, powder-liquid sequence, and lower powder/liquid ratios favour IB strength.

6.1.2 Thickness Swelling (TS) and Water Absorption (WA)

As shown in Figure 13, increasing the resin content from 3.0 to 8.0% lowered TS value for all resin application sequences and PPF/LPF ratios. An interaction also existed between resin application sequence and PPF/LPF ratio at each resin content. It was found that Sequence 2 (LPF-PPF) and the middle level of PPF/LPF ratio (65:35) resulted in lower TS value compared with other combinations.

Interaction between resin application sequence and PPF/LPF ratio at each resin content for WA is shown in Figure 14. The middle level of resin content (5.5%) resulted in lower WA values compared to the lower level (3.0%) and higher level (8.0%), regardless of resin application sequence and PPF/LPF ratio. At each resin content, lower WA panels seemed to be produced from either Sequence 1 (LPF-PPF-LPF) combined with the lower PPF/LPF ratio (50:50) or Sequence 3 (PPF-LPF) combined with the higher PPF/LPF ratio (80:20).

The WA test results imply that panels with lower WA appeared to result from the middle level of resin content (5.5%) combined with either the liquid-powder-liquid sequence and the lower powder/liquid ratio (50:50) or the PPF-LPF sequence and the higher powder/liquid ratio (80:20).

6.1.3 Modulus of Rupture (MOR) and Modulus of Elasticity (MOE)

Some interaction between resin application sequence and PPF/LPF ratio at each resin content was observed for dry MOR (Figure 15), dry MOE (Figure 16), and wet MOR (Figure 17). An increase in resin content improved all these static bending properties. Among the various combinations, it seemed that Sequence 3 (PPF-LPF) combined with the lower PPF/LPF ratio (50:50) resulted in higher dry MOR compared to other combinations. The same resin application sequence with the higher PPF/LPF ratio (80:20) yielded higher dry MOE. In terms of wet MOR, Sequence 2 (LPF-PPF) resulted in higher wet MOR regardless of resin application sequence at the lower resin content (3.0%). However, Sequence 2 with the lower PPF/LPF ratio (50:50) gave higher wet MOR at the middle level (5.5%) and higher (8.0%) resin contents.

In general, these results imply that higher resin content favours all static bending properties. At each resin content level, favourable combinations were observed for the PPF-LPF sequence with the lower powder/liquid ratio (50:50) for dry MOR, for the PPF-LPF sequence with the higher PPF/LPF ratio (80:20) for dry MOE, and for the LPF-PPF sequence with the lower PPF/LPF ratio (50:50) for wet MOR.

6.1.4 Edgewise Shear and Compression Shear

Edgewise shear strength as influenced by three main experimental variables is shown in Figure 18. The interaction between resin application sequence and PPF/LPF ratio followed different patterns at different resin contents. The higher edgewise shear strength was obtained at the lower resin content (3.0%) combined with Sequence 3 (PPF-LPF), regardless of PPF/LPF ratio.

Interactions between resin application sequence and PPF/LPF ratio were also observed for compression shear strength, as shown in Figure 19. An increase in resin content improved the strength property regardless of resin application sequence and PPF/LPF ratio. At each resin content, Sequence 3 (PPF-LPF) in combination with the lower PPF/LPF ratio (50:50) yielded higher compression shear strength compared with other combinations.

The above results indicate that the resin content significantly influences the compression shear and edgewise shear strength as compared with resin application sequence and PPF/LPF ratio. The PPF-LPF sequence at the lower level of resin content (3.0%), regardless of powder/liquid ratio, favours edgewise shear, while the same sequence with the lower powder/liquid ratio (50:50) at each resin content favours compression shear strength.

Table 5 Internal bond, water resistance, and static bending properties

Std	Run	Density[1] (kg/m^3)	OD Density[2] (kg/m^3)	Board MC[3] (%)	IB[4] (MPa)	TS[5] (%)	WA[6] (%)	Dry MOR[7] (Mpa)	Dry MOE[8] (MPa)	Wet MOR[9] (MPa)
11	1	666	614	8.4	0.221	15.5	29.1	28.1	3285	14.4
10	2	654	602	8.6	0.193	15.5	26.2	21.4	3226	12.2
4	3	691	637	8.5	0.418	13.4	28.2	31.4	3771	13.8
8	4	663	610	8.6	0.308	11.6	26.4	28.0	3676	13.0
16	5	662	609	8.6	0.244	12.9	25.1	32.0	4168	13.5
7	6	660	608	8.4	0.200	17.0	27.4	21.8	3220	10.7
15	8	669	616	8.6	0.316	13.1	25.4	29.8	3850	13.4
5	9	662	611	8.4	0.157	17.6	28.0	24.2	3343	11.6
13	10	659	607	8.5	0.276	14.4	26.1	29.0	3508	14.0
3	11	659	608	8.4	0.174	17.7	27.6	23.3	3218	11.7
9	12	684	630	8.5	0.363	14.0	26.5	26.1	3446	14.2
6	13	666	614	8.5	0.278	12.3	27.5	27.7	3560	13.5
1	14	675	624	8.2	0.173	17.1	28.8	21.4	2987	11.4
14	15	667	614	8.6	0.226	12.8	25.6	23.0	3465	13.9
2	16	675	622	8.6	0.343	12.6	27.9	29.6	3809	15.3
12	17	673	621	8.2	0.261	14.7	25.9	27.2	3654	12.7

[1]Density: board density after conditioning (average of all IB and MOR/MOE specimens per panel)
[2]OD Density: oven-dried board density (estimated from board density and MC per panel)
[3]Board MC: board moisture content (average of 3 specimens per panel)
[4]IB: internal bond strength (average of 5-9 specimens per panel)
[5]TS: 24-h thickness swelling (average of 2 specimens per panel)
[6]WA: 24-h water absorption (average of 2 specimens per panel)
[7]Dry MOR: dry modulus of rupture (average of 2 specimens per panel)
[8]Dry MOE: modulus of elasticity (average of 2 specimens per panel)
[9]Wet MOR: wet modulus of rupture (average of 2 specimens per panel)

Table 6 Edgewise shear and compression shear properties and non-destructive test results

Std Order	Run Order	Edgewise Shear[1] (MPa)	Compression Shear[2] (Mpa)	TORBEND Test	
				Modulus of Elasticity[3] (MPa)	Shear Modulus of Elasticity (through Thickness)[4] (MPa)
11	1	1161	2.97	2635	1992
10	2	1137	2.37	2484	1891
4	3	1011	3.70	2649	2132
8	4	1081	3.25	2699	2022
16	5	1216	2.88	2708	1993
7	6	1200	2.17	2790	2026
15	8	1168	3.05	2473	2008
5	9	1053	2.08	2627	1939
13	10	1094	2.95	2822	2021
3	11	1138	2.43	2600	2015
9	12	1162	3.14	2772	2108
6	13	1217	3.09	2657	2079
1	14	1109	2.31	2569	1958
14	15	1080	2.47	2703	2050
2	16	1132	3.28	2608	2068
12	17	1076	2.88	2405	1966

[1]Average of 2 specimens per panel
[2]Average of 8 specimens per panel
[3]Average of all panels per run
[4]Average of all panels per run

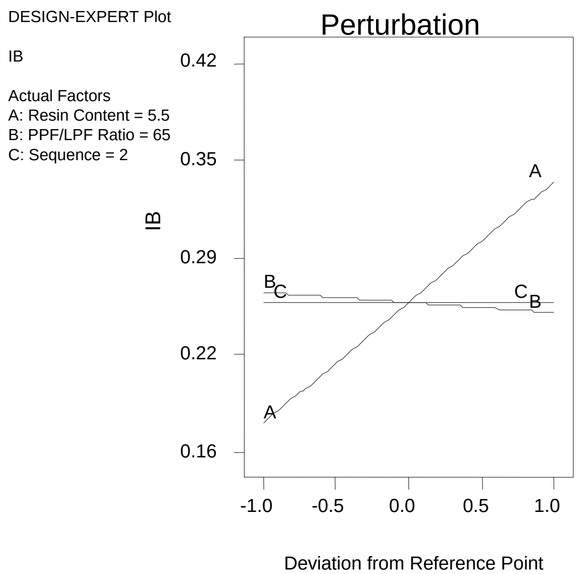


Figure 4 Internal bond strength as influenced by resin application sequence, powder/liquid ratio, and resin content (the -1, 0 and +1 on the x-axis of the perturbation plot represent the lowest, middle, and highest levels of each variable, respectively)

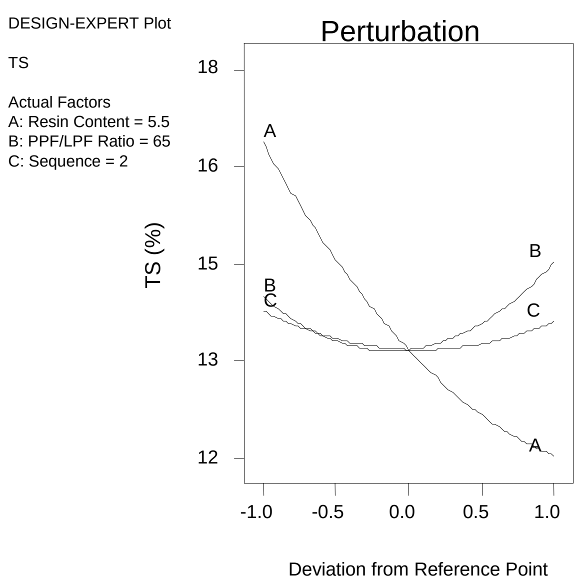


Figure 5 Thickness swelling as influenced by resin application sequence, powder/liquid ratio, and resin content (the -1, 0, and +1 on the x-axis of the perturbation plot represent the lowest, middle, and highest levels of each variable, respectively)

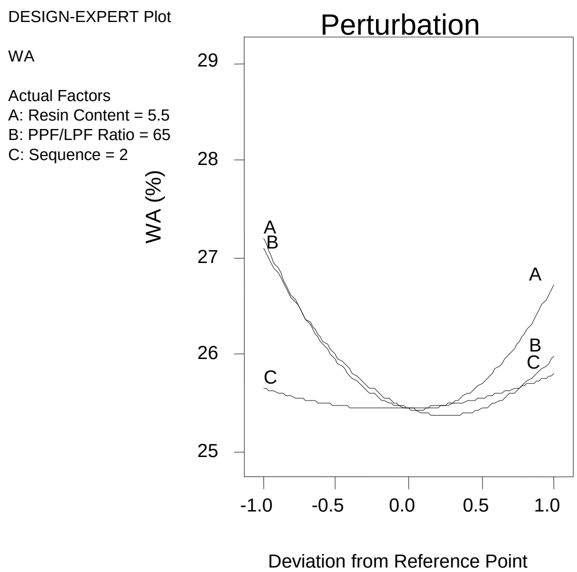


Figure 6 Water absorption as influenced by resin application sequence, powder/liquid ratio, and resin content (the -1, 0, and +1 on the x-axis of the perturbation plot represent the lowest, middle, and highest levels of each variable, respectively)

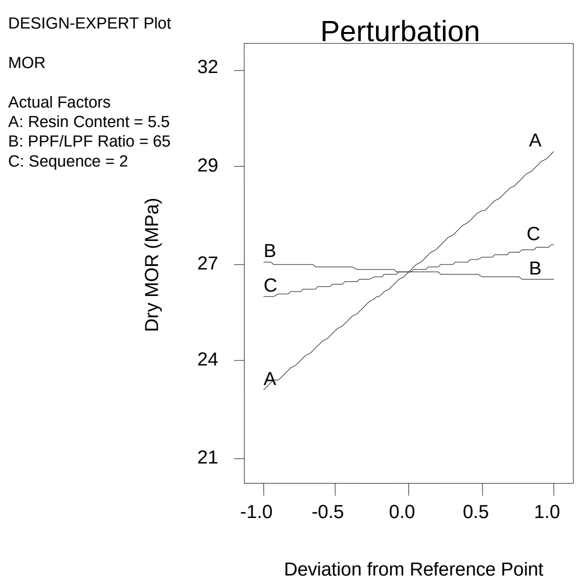


Figure 7 Dry modulus of rupture as influenced by resin application sequence, powder/liquid ratio, and resin content (the -1, 0, and +1 on the x-axis of the perturbation plot represent the lowest, middle, and highest levels of each variable, respectively)

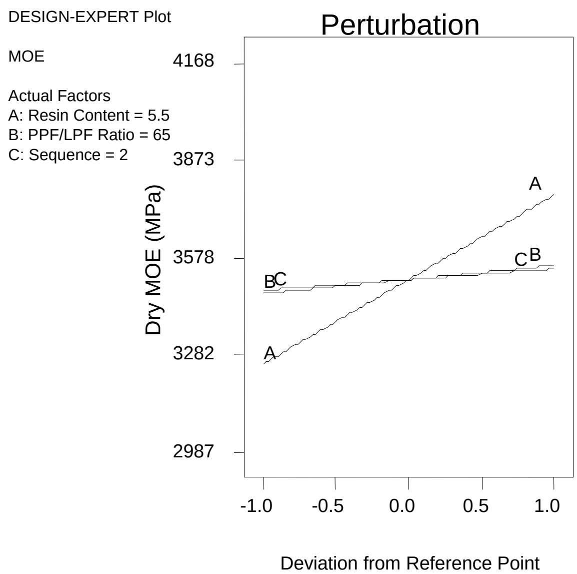


Figure 8 Dry modulus of elasticity as influenced by resin application sequence, powder/liquid ratio, and resin content (the -1, 0, and +1 on the x-axis of the perturbation plot represent the lowest, middle, and highest levels of each variable, respectively)

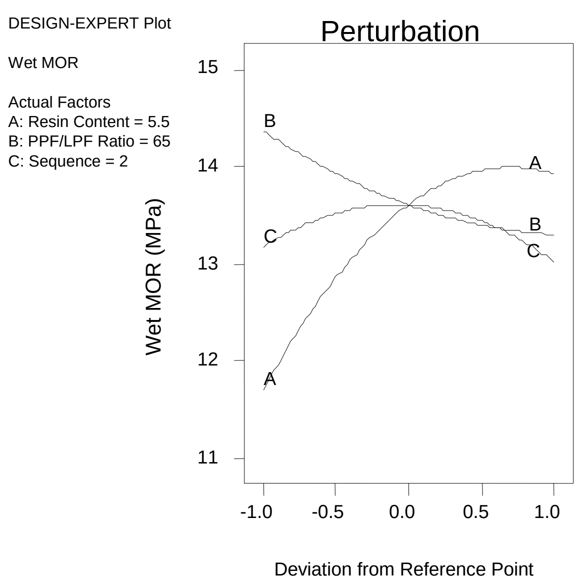


Figure 9 Wet modulus of rupture as influenced by resin application sequence, powder/liquid ratio, and resin content (the -1, 0, and +1 on the x-axis of the perturbation plot represent the lowest, middle, and highest levels of each variable, respectively)

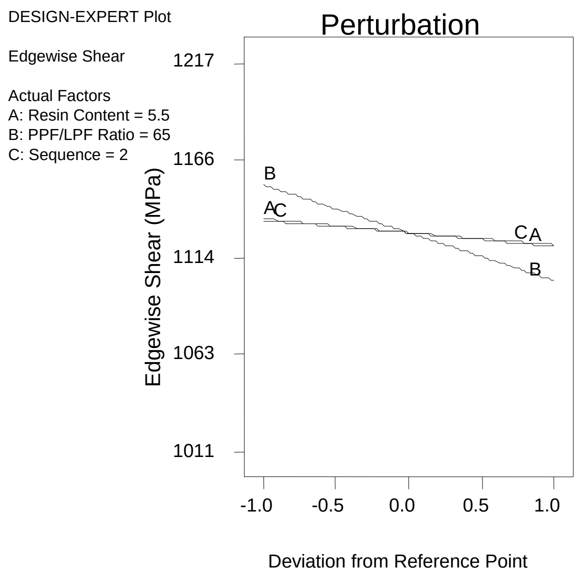


Figure 10 Edgewise shear strength as influenced by resin application sequence, powder/liquid ratio, and resin content (the -1, 0, and +1 on the x-axis of the perturbation plot represent the lowest, middle, and highest levels of each variable, respectively)

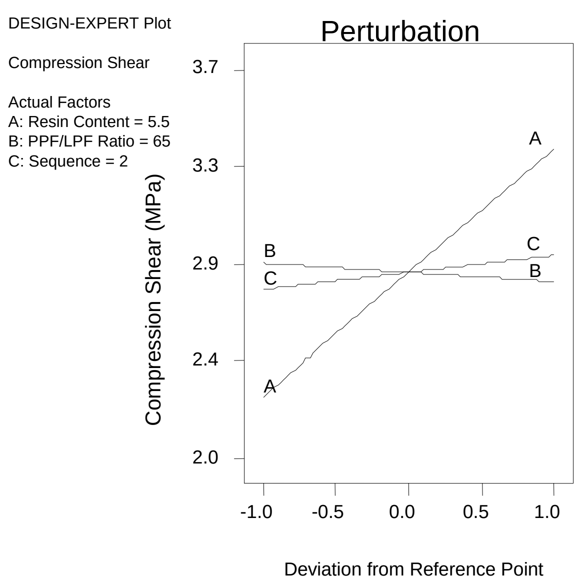


Figure 11 Compression shear strength as influenced by resin application sequence, powder/liquid ratio, and resin content (the -1, 0, and +1 on the x-axis of the perturbation plot represent the lowest, middle, and highest levels of each variable, respectively)

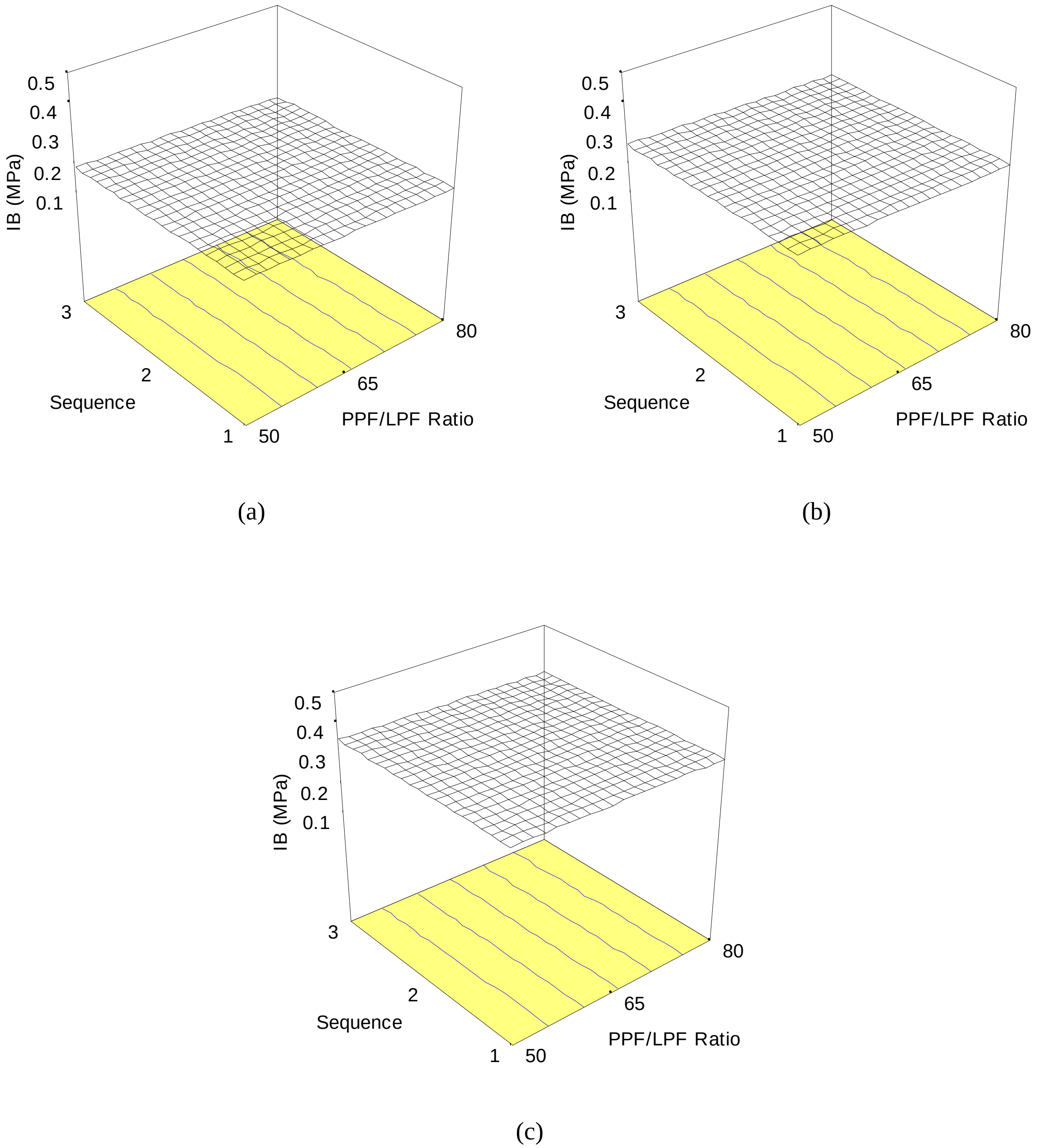


Figure 12 Internal bond strength as influenced by the interaction of resin application sequence and powder/liquid ratio at different resin contents: (a) 3.0%, (b) 5.5%, and (c) 8.0%

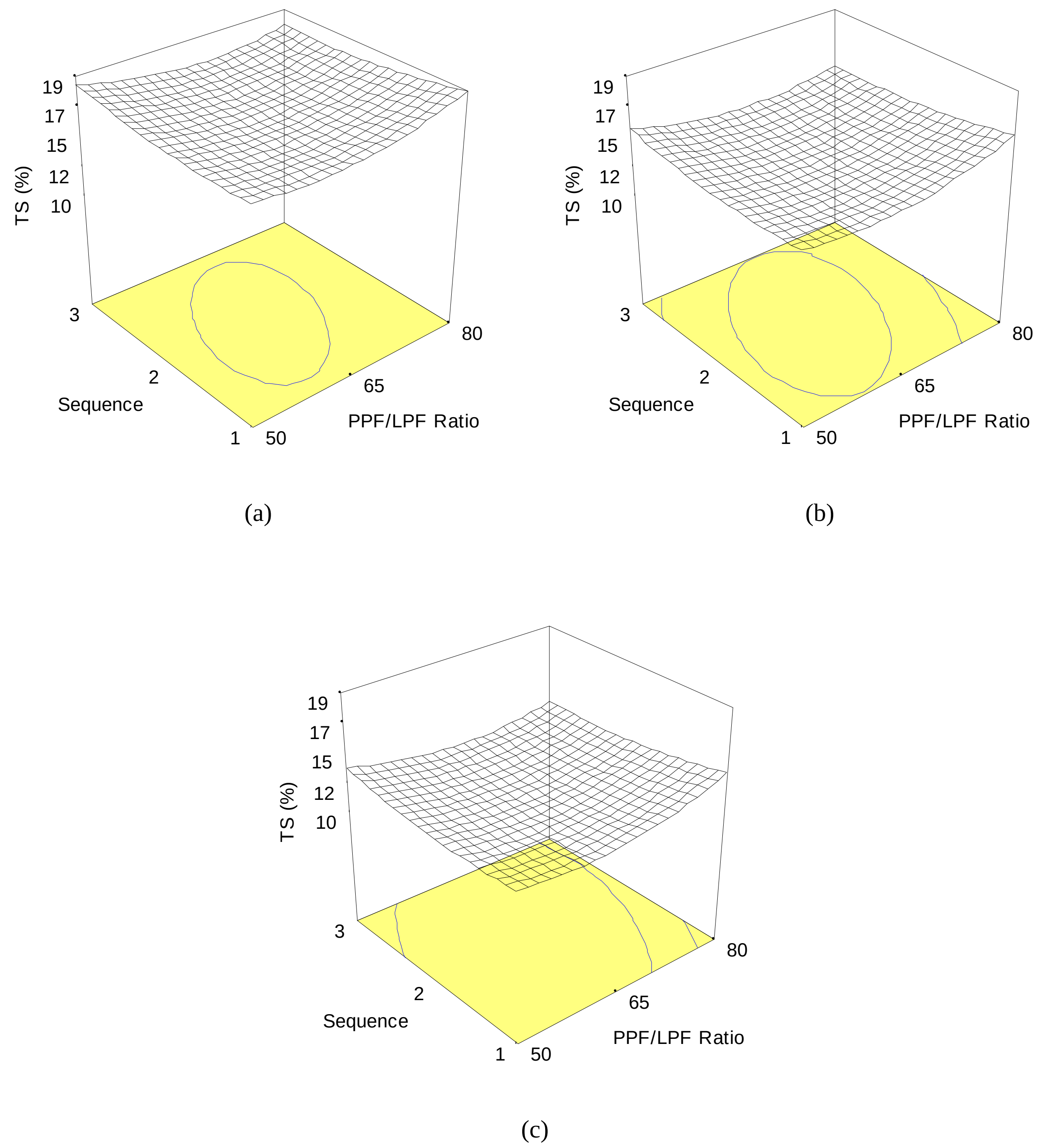


Figure 13 Thickness swelling as influenced by the interaction of resin application sequence and powder/liquid ratio at different resin contents: (a) 3.0%, (b) 5.5%, and (c) 8.0%

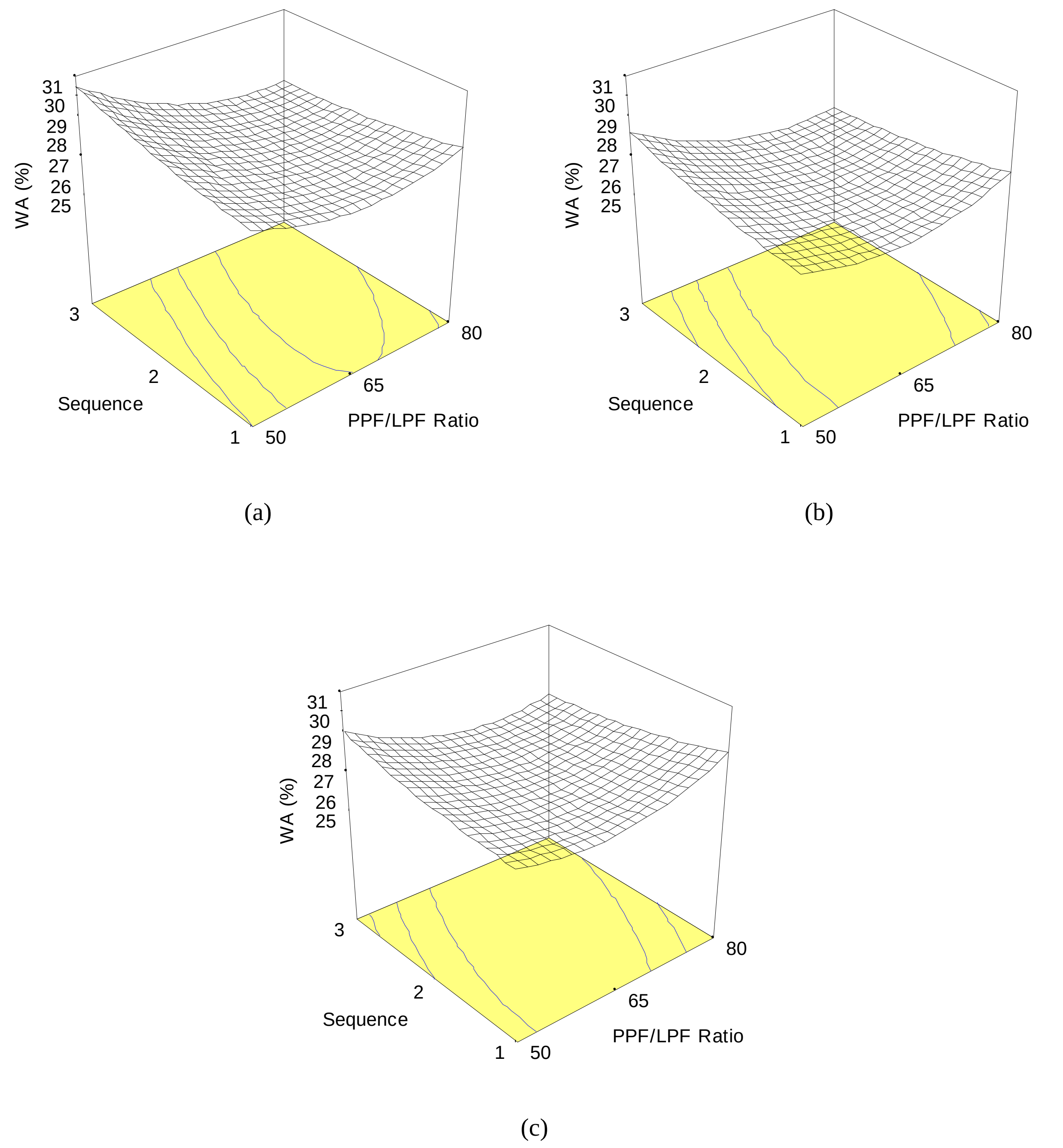


Figure 14 Water absorption as influenced by the interaction of resin application sequence and powder/liquid ratio at different resin contents: (a) 3.0%, (b) 5.5%, and (c) 8.0%

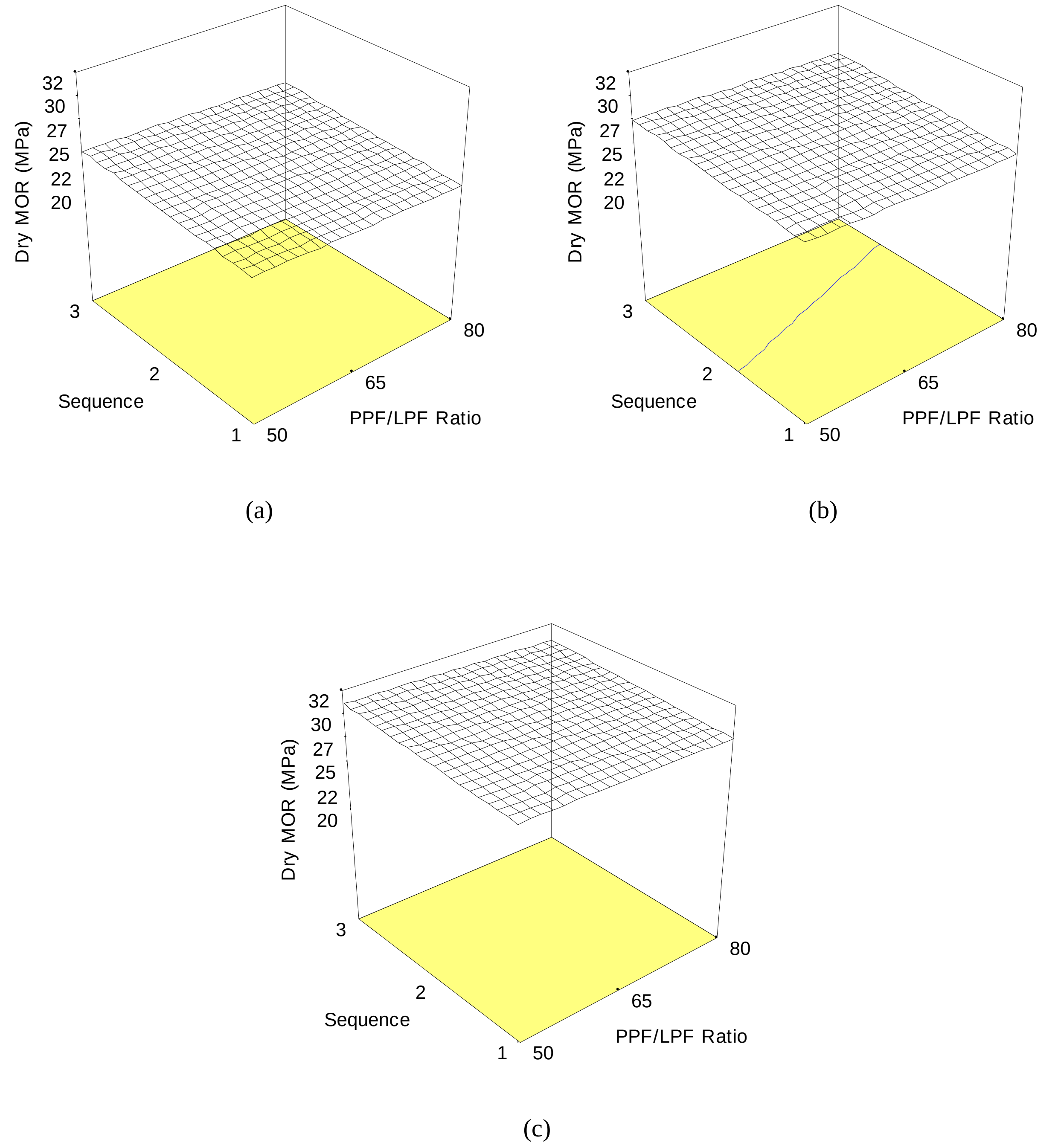
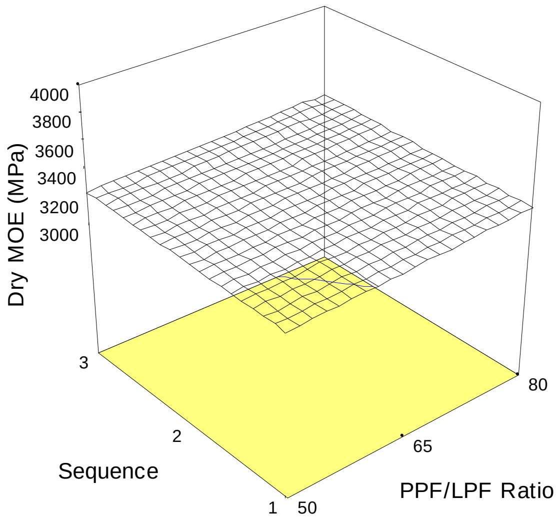
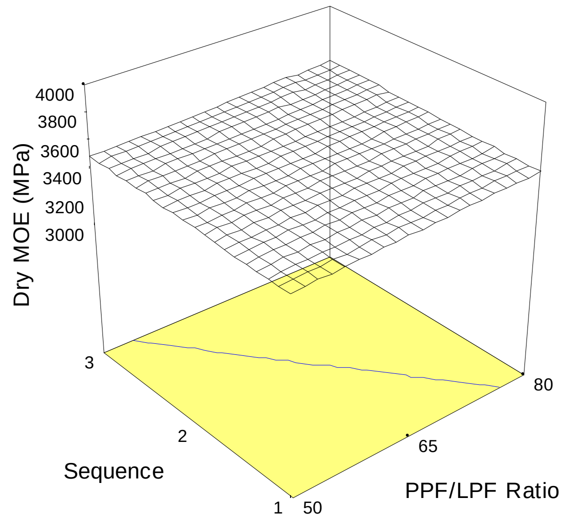


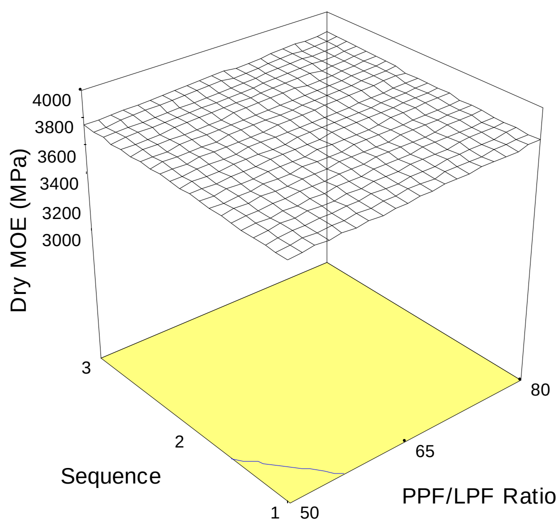
Figure 15 Dry modulus of rupture as influenced by the interaction of resin application sequence and powder/liquid ratio at different resin contents: (a) 3.0%, (b) 5.5%, and (c) 8.0%



(a)

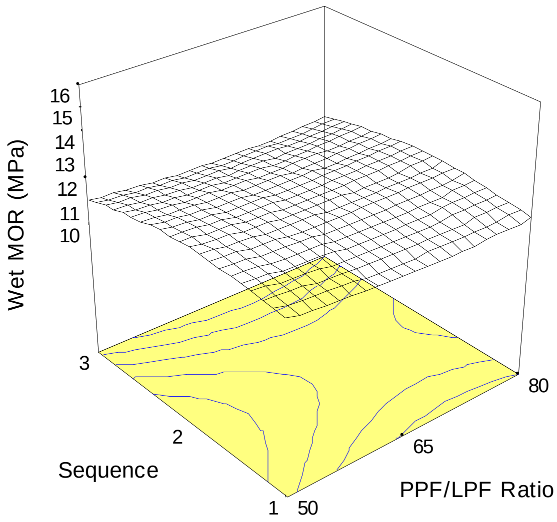


(b)

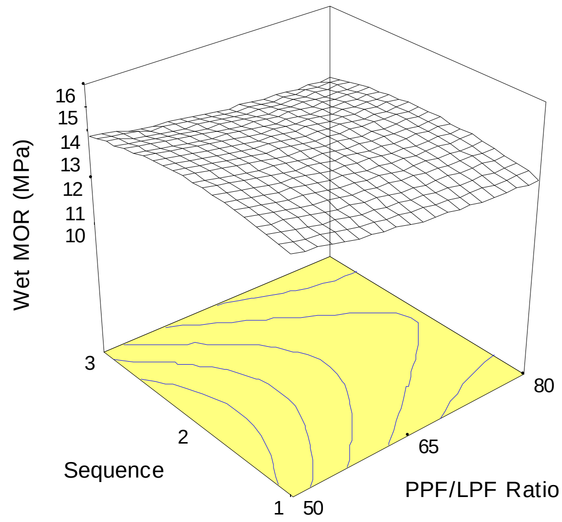


(c)

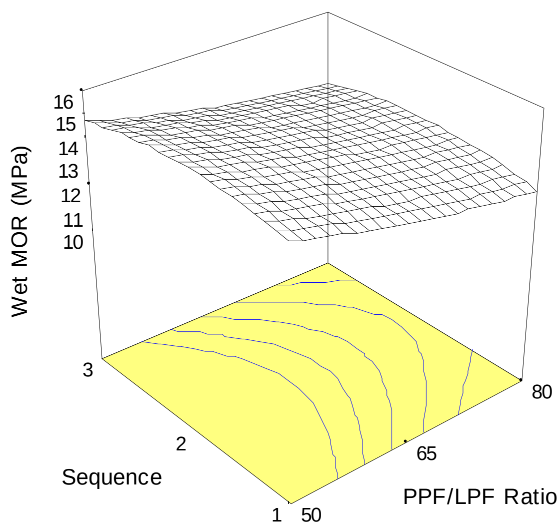
Figure 16 Dry modulus of elasticity as influenced by the interaction of resin application sequence and powder/liquid ratio at different resin contents: (a) 3.0%, (b) 5.5%, and (c) 8.0%



(a)



(b)



(c)

Figure 17 Wet modulus of rupture as influenced by the interaction of resin application sequence and powder/liquid ratio at different resin contents: (a) 3.0%, (b) 5.5%, and (c) 8.0%

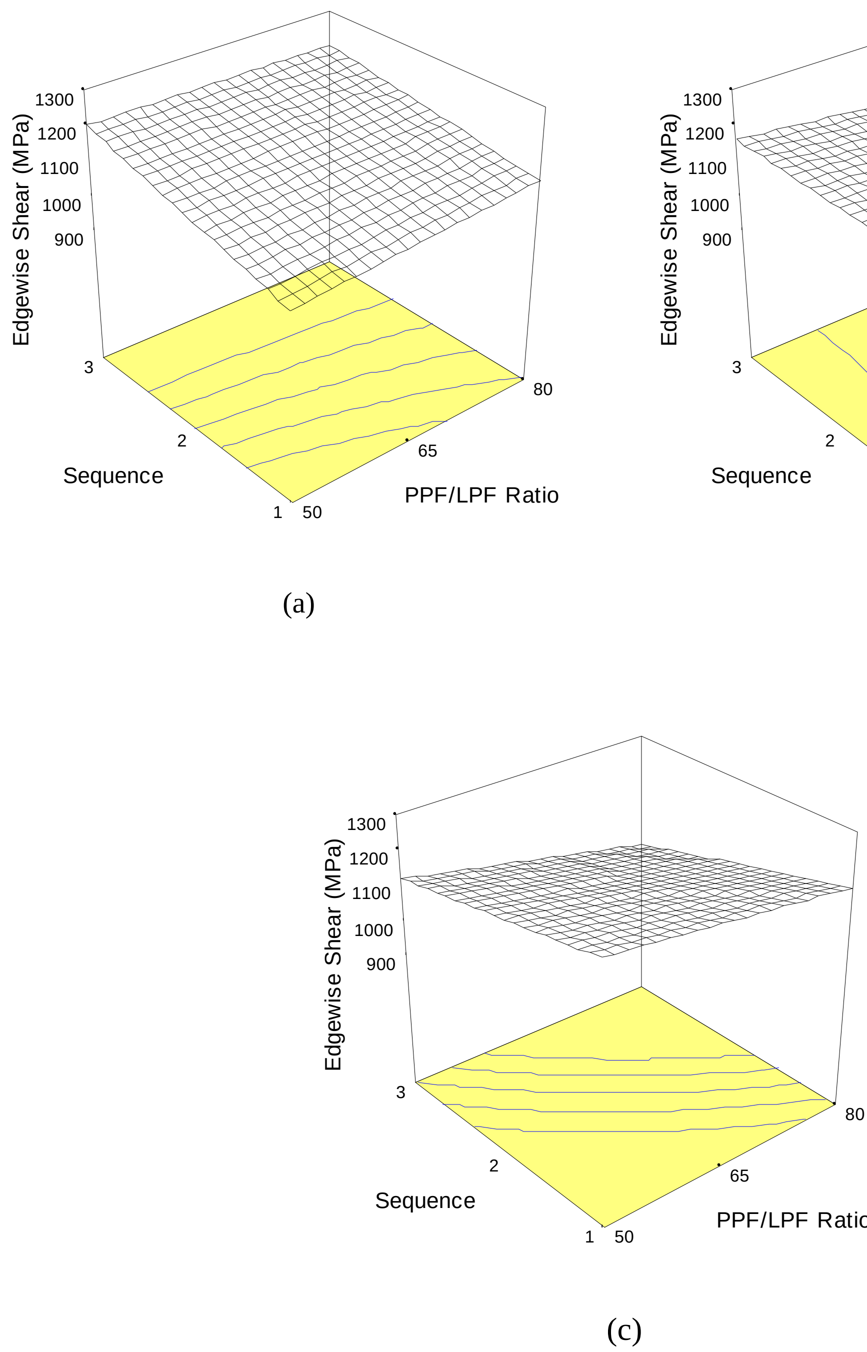
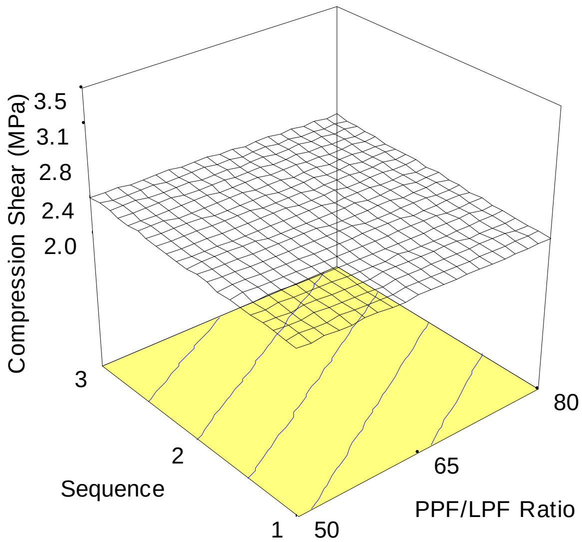
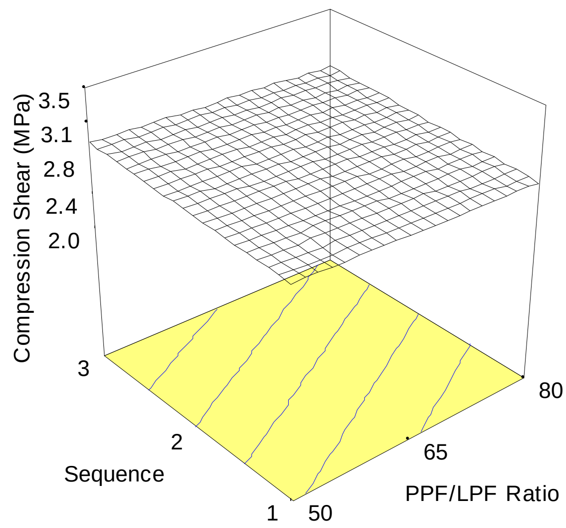


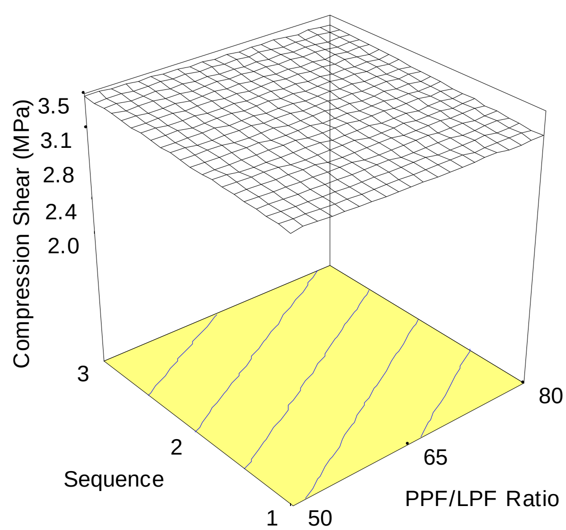
Figure 18 Edgewise shear strength as influenced by the interaction of resin application sequence and powder/liquid ratio at different resin contents: (a) 3.0%, (b) 5.5%, and (c) 8.0%



(a)



(b)



(c)

Figure 19 Compression shear strength as influenced by the interaction of resin application sequence and powder/liquid ratio at different resin contents: (a) 3.0%, (b) 5.5%, and (c) 8.0%

6.2 Surface Response Models

Response surface methodology (RSM) is able to establish models for process optimization. In this study, Box-Behnken, a central composite design (CCD) available for RSM was selected for the experiment. The results of sequential model sum of squares, lack of fit tests, and model summary statistics suggest that significant models would be the linear model for IB, dry MOR, dry MOE, and compression shear strength, the quadric model for TS, WA, and wet MOR, and the 2FI model (two factor interaction) for edgewise shear of elasticity. Model graphs for each response (panel property) at the corresponding model were shown in Figures 4-19.

Based on the analysis of variance (ANOVA) for response surface models, the equations in terms of actual factors can be established to estimate board properties. Each individual panel property could be predicted as shown below. In these models, resin content varies between 3 and 8%, powder-to-liquid ratio varies between 50 (for 50:50) and 80 (for 80:20), while resin application sequence can be selected only at 1 for LPF-PPF-LPF, 2 for LPF-PPF, or 3 for PPF-LPF.

IB (MPa)

= + 0.112
+ 0.032 x [Resin Content]
- 4.500E-004 x [PPF/LPF Ratio]
- 1.250E-004 x [Sequence]

TS (%)

= + 39.19
- 2.40 x [Resin Content]
- 0.54 x [PPF/LPF Ratio]
+ 0.38 x [Sequence]
+ 0.13 x $[\text{Resin Content}]^2$
+ 4.83E-003 x $[\text{PPF/LPF Ratio}]^2$
+ 0.52 x $[\text{Sequence}]^2$
+ 8.00E-004 x [Resin Content] x [PPF/LPF Ratio]
- 0.01 x [Resin Content] x [Sequence]
- 0.04 x [PPF/LPF Ratio] x [Sequence]

WA (%)

= + 54.02
- 3.33 x [Resin Content]
- 0.62 x [PPF/LPF Ratio]
+ 2.32 x [Sequence]
+ 0.24 x $[\text{Resin Content}]^2$
+ 4.81E-003 x $[\text{PPF/LPF Ratio}]^2$
+ 0.28 x $[\text{Sequence}]^2$
+ 0.01 x [Resin Content] x [PPF/LPF Ratio]
- 0.04 x [Resin Content] x [Sequence]
- 0.05 x [PPF/LPF Ratio] x [Sequence]

Dry MOR (MPa)

= + 18.95
+ 1.30 x [Resin Content]
- 0.02 x [PPF/LPF Ratio]
+ 0.71 x [Sequence]

Dry MOE (MPa)

= + 2698.18
+ 102.40 x [Resin Content]
+ 2.85 x [PPF/LPF Ratio]
+ 32.50 x [Sequence]

Wet MOR (MPa)

= + 8.69
+ 2.82 x [Resin Content]
- 0.14 x [PPF/LPF Ratio]
+ 1.72 x [Sequence]
- 0.15 x $[\text{Resin Content}]^2$
+ 1.17E-003 x $[\text{PPF/LPF Ratio}]^2$
- 0.59 x $[\text{Sequence}]^2$
- 0.01 x [Resin Content] x [PPF/LPF Ratio]
- 0.04 x [Resin Content] x [Sequence]
+ 5.00E-003 x [PPF/LPF Ratio] x [Sequence]

Edgewise shear (MPa)

= + 466.78
+ 118.65 x [Resin Content]
+ 5.82 x [PPF/LPF Ratio]
+ 214.28 x [Sequence]
- 1.00 x [Resin Content] x [PPF/LPF Ratio]
- 28.30 x [Resin Content] x [Sequence]
- 1.00 x [PPF/LPF Ratio] x [Sequence]

Compression shear (MPa)

= + 1.65
+ 0.22 x [Resin Content]
- 2.67 x [PPF/LPF Ratio]
+ 0.07 x [Sequence]

The factors that were not significant at a 0.05 level were eliminated with Backward Elimination Regression. The hierarchical terms such as PPF/LPF ratio were added to TS, resin content, and PPF/LPF ratio to WA, and resin content and application sequence were added to edgewise shear strength. Each individual panel property could be predicted as follows with response surface reduced models:

IB (MPa)

= 0.083 + 0.032 x [Resin Content]

TS (%)

= 42.00 - 2.36 x [Resin Content] - 0.61 x [PPF/LPF Ratio] + 0.13 x [Resin Content]^2 + 4.83E-003 x [PPF/LPF Ratio]^2

WA (%)

= 56.20 - 2.74 x [Resin Content] - 0.66 x [PPF/LPF Ratio] + 0.24 x [Resin Content]^2 + 4.81E-003 x [PPF/LPF Ratio]^2

Dry MOR (MPa)

= 19.35 + 1.30 x [Resin Content]

Dry MOE (MPa)

= 2948.42 + 102.40 x [Resin Content]

Wet MOR (MPa)

= 8.97 + 2.12 x [Resin Content] - 0.04 x [PPF/LPF Ratio] - 0.15 x [Resin Content]^2

Edgewise shear (MPa)

= 844.86 + 53.65 x [Resin Content] + 149.27 x [Sequence] - 28.30 x [Resin Content] x [Sequence]

Compression shear (MPa)

= 1.62 + 0.22 x [Resin Content]

ANOVA for response surface reduced linear, quadric, and 2FI models indicated that, except for edgewise shear strength, the above models for predicting each panel property were significant (Prob >F less than 0.05). In addition, the underlined variables in each equation were significant model terms (Prob >F less than 0.05).

6.3 Correlations between Panel Properties

Correlations between destructive test results and non-destructive results, and between destructive and non-destructive test results are illustrated in Figures 20-24. Among the destructive tests, the most significant correlation was observed for IB and compression shear strength (R^2 = 0.70), as shown in Figure 20. For the non-destructive tests, the correlation between TORBEND MOE (modulus of elasticity) and TORBEND G (shear modulus of elasticity) seemed to be apparent, indicated by the regression coefficient (R^2 = 0.40) (Figure 21).

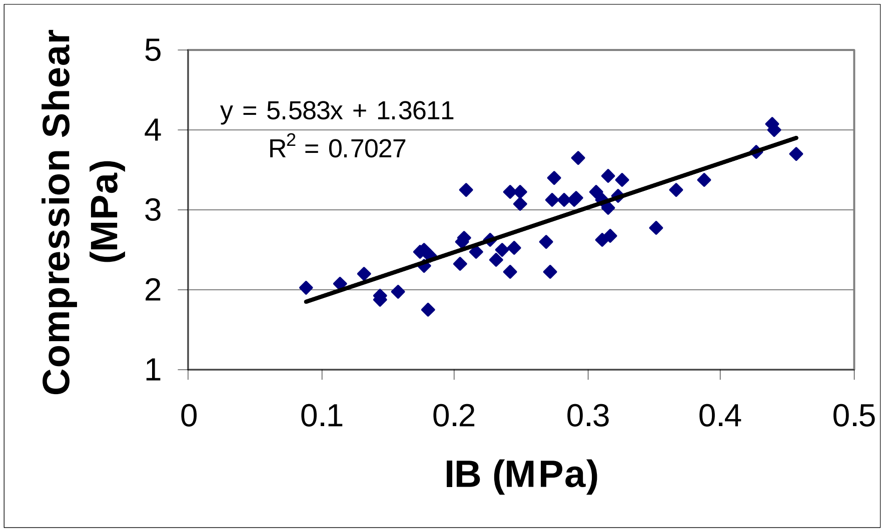


Figure 20 Correlation between internal bond strength (IB) and compression shear strength measured by destructive test

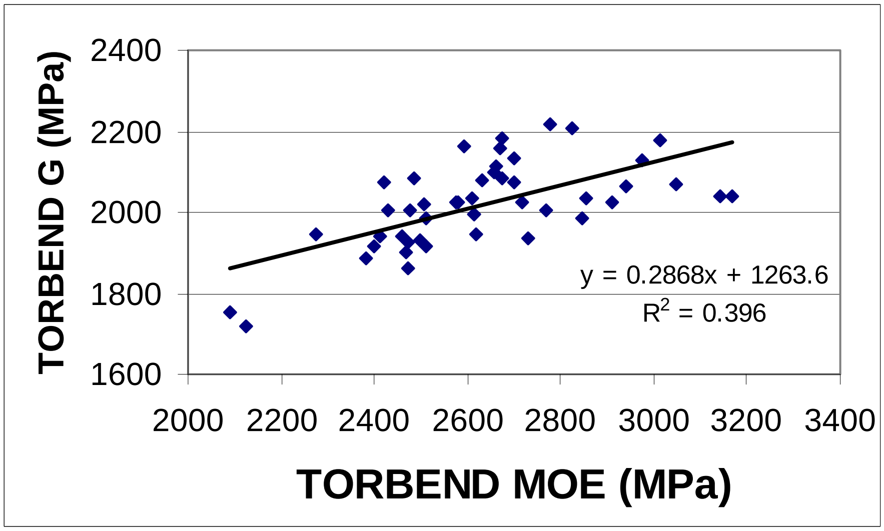


Figure 21 Correlation between modulus of elasticity (MOE) and shear modulus of elasticity (G) measured by non-destructive test (TORBEND)

A comparison of non-destructive tests indicated that there was almost no correlation between MOE from the static bending test and MOE from the TORBEND test as illustrated in Figure 22. Lau and Tardif (1996) observed an excellent correlation (R^2 = 0.97) between static MOE obtained using cantilever bending method (Lau and Tardif 1996) and MOE obtained by TORBEND vibration. An apparent correlation (R^2 = 0.82) was also found between MOE measured from the pure moment bending test (ASTM D 3043C) and TORBEND MOE. In addition, Lau and Tardif (1996) also observed a significant correlation (R^2 = 0.91) between TORBEND G and shear modulus (ASTM D 3044). All the above tests were conducted on large-size OSB and waferboard boards with widths ranging from 450 to 610 mm and test spans from 560 to 1220 mm.

In the current study, however, 540 mm x 540 mm randomly oriented strand boards were used in the TORBEND test, while small specimens (316 mm x 75 mm) were used in the static bending test (CSA O437.1-93). Thus, the poor correlations of TORBEND MOE or G with other panel properties observed in the current study were probably caused by within-panel variations. It was expected that an increase in the test number of specimens would improve the correlation coefficients.

A correlation also seemed to exist between TORBEND G and IB strength (R^2 = 0.26), as shown in Figure 23. A similar degree of correlation was noticed between TORBEND G and compression shear strength (R^2 = 0.28), as illustrated in Figure 24.

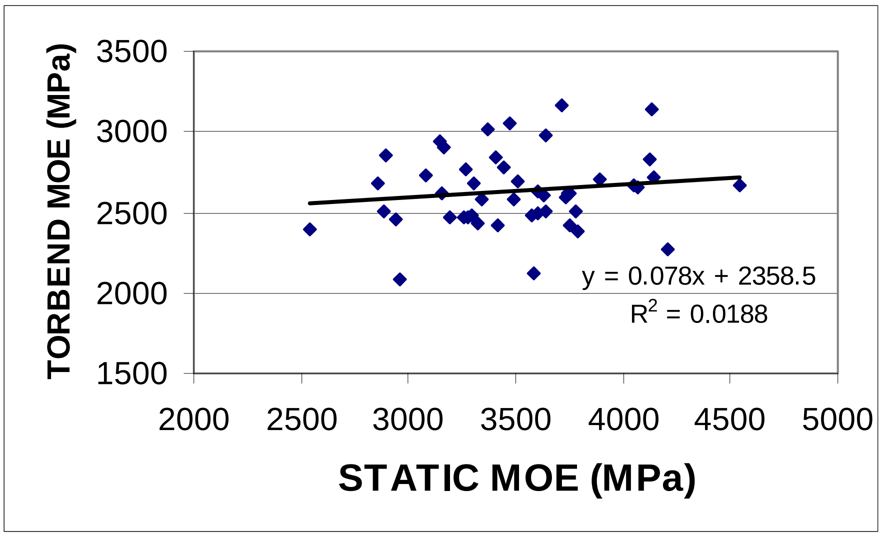


Figure 22 Correlation between modulus of elasticity (MOE) measured using static bending test and modulus of elasticity (MOE) measured by TORBEND vibration

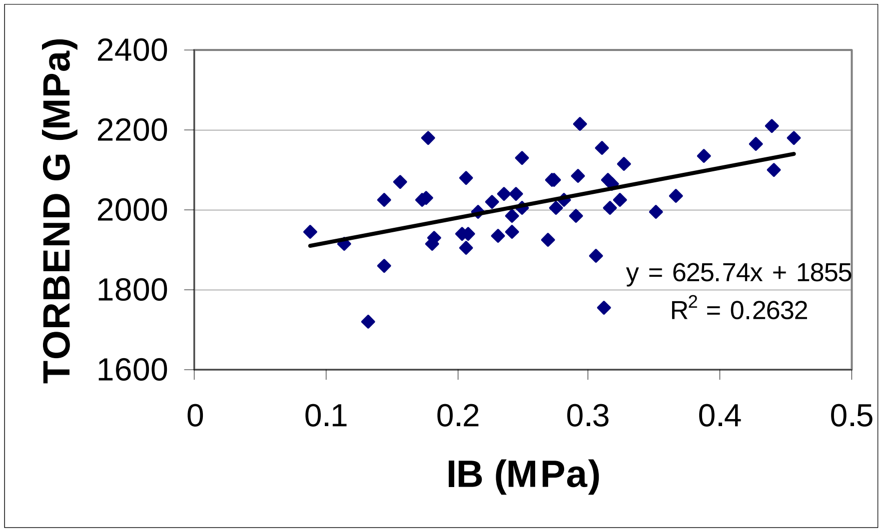


Figure 23 Correlation between internal bond strength (IB) measured by destructive test and shear modulus of elasticity (G) measured by TORBEND vibration

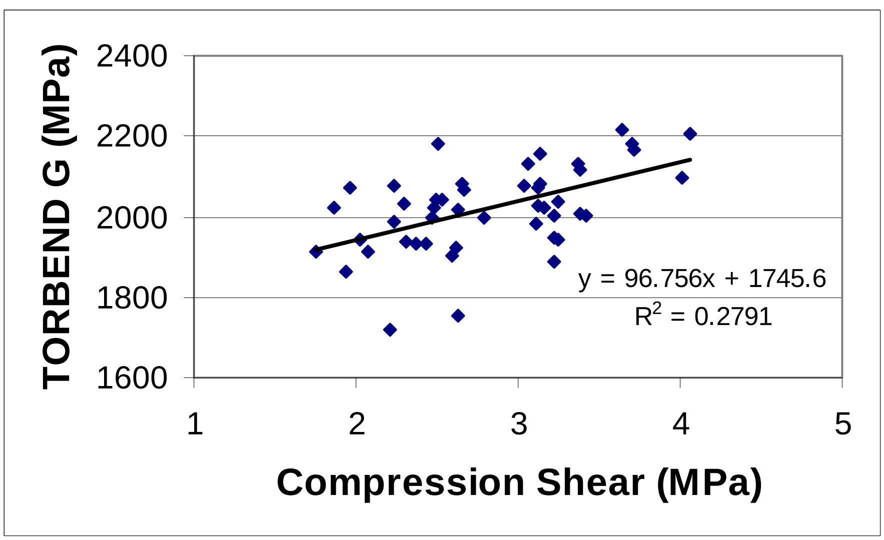


Figure 24 Correlation between compression shear strength measured by destructive test and shear modulus of elasticity (G) measured by TORBEND vibration

6.4 Resin Coverage and its Correlation with Panel Properties

Resin coverage on strand surfaces measured by an image analysis system is shown in Appendix X and is summarized in Table 7. All the measurements were made with surface strands from each run. The average resin coverage was 14.84% for all 16 runs, ranging from 8.42 to 22.17%. It was noted that there was a significant variation within each run, indicated by the coefficient of variation (34.85 to 54.43%). The resin coverage as influenced by resin content, PPF/LPF ratio, and resin application sequence is illustrated in Figure 25. This figure shows that resin coverage was significantly affected by resin content, while it was slightly influenced by the other two resin variables.

The interaction between resin content and resin PPF/LPF ratio is given in Figures 26. Resin coverage significantly increased with increasing resin content (3 to 8%) regardless of resin application sequence and PPF/LPF ratio. In sequence 1 (LPF-PPF-LPF), the resin coverage increased as PPF/LPF ratio decreased from 80:20 to 50:50; however, the reverse trend was observed in sequence 3 (PPF-LPF). In general, the higher resin coverage resulted from the following combinations:

- At 3.0% resin (lower level), Sequence 3 (PPF-LPF) with 80:20 PPF/LPF ratio (higher level)
- At 5.5% resin (middle level), Sequence 3 (PPF-LPF) with 80:20 PPF/LPF ratio (higher level) or Sequence 1 (LPF-PPF-LPF) with 50:50 PPF/LPF ratio (lower level)
- At 8.0% resin (higher level), Sequence 1 (LPF-PPF-LPF) with 50:50 PPF/LPF ratio (lower level)

Statistical analysis indicated that the significant model for resin coverage was 2FI (two factor interaction). The model terms included all three variables and their interactions.

Resin coverage (%) = + 10.95
+ 5.02 x [Resin content]
- 0.17 x [PPF/LPF Ratio]
- 7.82 x [Sequence]
- 0.03 x [Resin Content] x [PPF/LPF Ratio]
- 0.59 x [Resin Content] x [Sequence]
+ 0.15 x [PPF/LPF Ratio] x [Sequence]

Some model terms that were not significant at a 0.05 level were removed with Backward Elimination Regression, including PPF/LPF ratio and some interactions between resin content and PPF/LPF ratio or resin application sequence. The significant model terms were resin content (3% to 8%), resin application sequence (1, 2, or 3), and the interaction of PPF/LPF ratio (50 to 80) with resin application sequence. The response surface reduced model for resin coverage becomes:

Resin coverage (%) = + 27.36
+ 2.04 x [Resin content]
- 0.33 x [PPF/LPF Ratio]
- 11.07 x [Sequence]
+ 0.15 x [PPF/LPF Ratio] x [Sequence]

Table 7 Summary of resin coverage

Std Order	Run Order	Resin (%)	PPF/ LPF Ratio	Resin Application Sequence	Resin Coverage (%)				
					Avg.	Std.	C.V.	Min	Max
11	1	5.5	50	3 (PPF-LPF)	15.87	6.00	37.81	2.82	35.76
10	2	5.5	80	1 (LPF-PPF-LPF)	14.19	5.50	38.77	5.29	28.67
4	3	8.0	80	2 (LPF-PPF)	19.02	6.84	35.98	7.52	38.89
8	4	8.0	65	3 (PPF-LPF)	15.76	6.20	39.35	3.49	32.90
16	5	**5.5**	**65**	2 (LPF-PPF)	16.89	6.29	37.22	4.69	35.93
7	6	3.0	65	3 (PPF-LPF)	10.00	3.48	34.85	4.56	20.48
15	8	**5.5**	**65**	2 (LPF-PPF)	11.92	4.47	37.50	3.49	24.80
5	9	3.0	65	1 (LPF-PPF-LPF)	9.47	3.49	36.81	3.25	19.34
13	10	**5.5**	**65**	2 (LPF-PPF)	13.26	5.17	38.96	2.25	31.99
3	11	3.0	80	2 (LPF-PPF)	9.42	5.15	54.63	2.23	27.06
9	12	5.5	50	1 (LPF-PPF-LPF)	19.11	7.27	38.05	3.80	42.60
6	13	8.0	65	1 (LPF-PPF-LPF)	21.15	7.83	37.05	6.26	39.71
1	14	3.0	50	2 (LPF-PPF)	8.42	4.57	54.24	2.15	24.03
14	15	**5.5**	**65**	2 (LPF-PPF)	14.75	5.23	35.47	5.49	33.52
2	16	8.0	50	2 (LPF-PPF)	22.17	9.51	42.91	5.60	48.88
12	17	5.5	80	3 (PPF-LPF)	16.06	7.14	44.46	3.46	37.39

Correlations of resin coverage on strand surfaces with panel mechanical and physical properties are illustrated in Figures 27-36. These linear regression plots show some apparent correlations for TS ($R^2 = 0.45$), followed by IB ($R^2 = 0.42$), compression shear ($R^2 = 0.39$), and TORBEND G (shear modulus of elasticity measured by TORBEND method) ($R^2 = 0.39$). Since the resin coverage correlated significantly to resin content, as shown in Figure 26, the results imply that the availability for bonding of more resin between strands, as indicated by the higher resin coverage, was responsible for the improved panel properties. As indicated by the R-squared value, some correlation also seemed to exist between resin coverage and dry MOR ($R^2 = 0.25$), wet MOR ($R^2 = 0.25$), or dry MOE ($R^2 = 0.18$); this means higher resin coverage results in better board static bending properties. However, no correlation was observed for WA, edgewise shear, or TORBEND MOE.

It is well known that wax in either slack or emulsion form acts as a carrier or anchoring agent for improving powder resin's retention over strand surfaces. The amount of wax should be increased with increased powder resin application levels in order to maintain a similar level of powder resin retention. However, use of high quantity wax will interfere with resin bonding quality. This problem may be solved with powder and liquid combination binder system. In this resin system, the liquid resin is expected to act like wax to stabilize the powder on the strand surface. Thus, the use of a small amount of liquid resin would help retain a large quantity of powder resin when higher resin usage is required.

It was assumed that liquid resin could stabilize the powder resin on the strand surfaces when the liquid is applied either prior to or after the powder application. However, the impact on the powder retention could be different. In this study, three resin application sequences were investigated. In general, slightly higher resin coverage was observed for the liquid-powder-liquid, followed by the liquid-powder, and finally powder-liquid sequence at each resin content and powder/liquid ratio (Figure 26). However, the influence of resin application sequence on resin coverage was limited compared with resin content.

With respect to resin coverage, it should be noted that an image analysis system cannot take the thickness or height of resin spots into account. This means that higher resin coverage does not necessarily correspond to higher resin loading or retention levels measured by resin weight, especially when a liquid and powder resin combination binder system is used. This is probably why some panel properties are less sensitive to resin coverage variations. With a combination resin system, it would be more practical to use both resin coverage and resin loading methods to evaluate the resin distribution and efficiency over the strand surfaces.

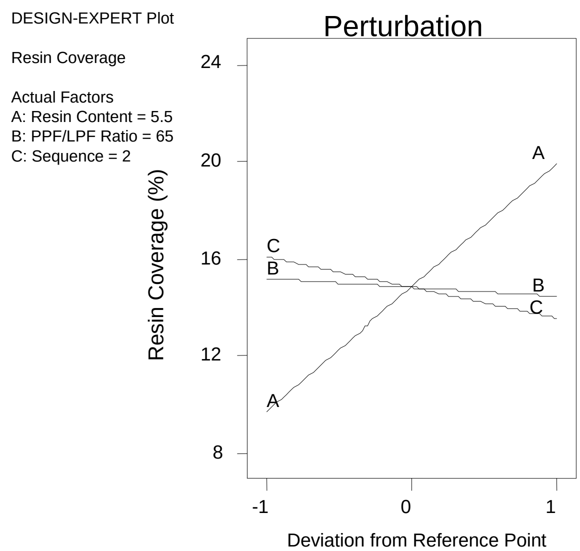
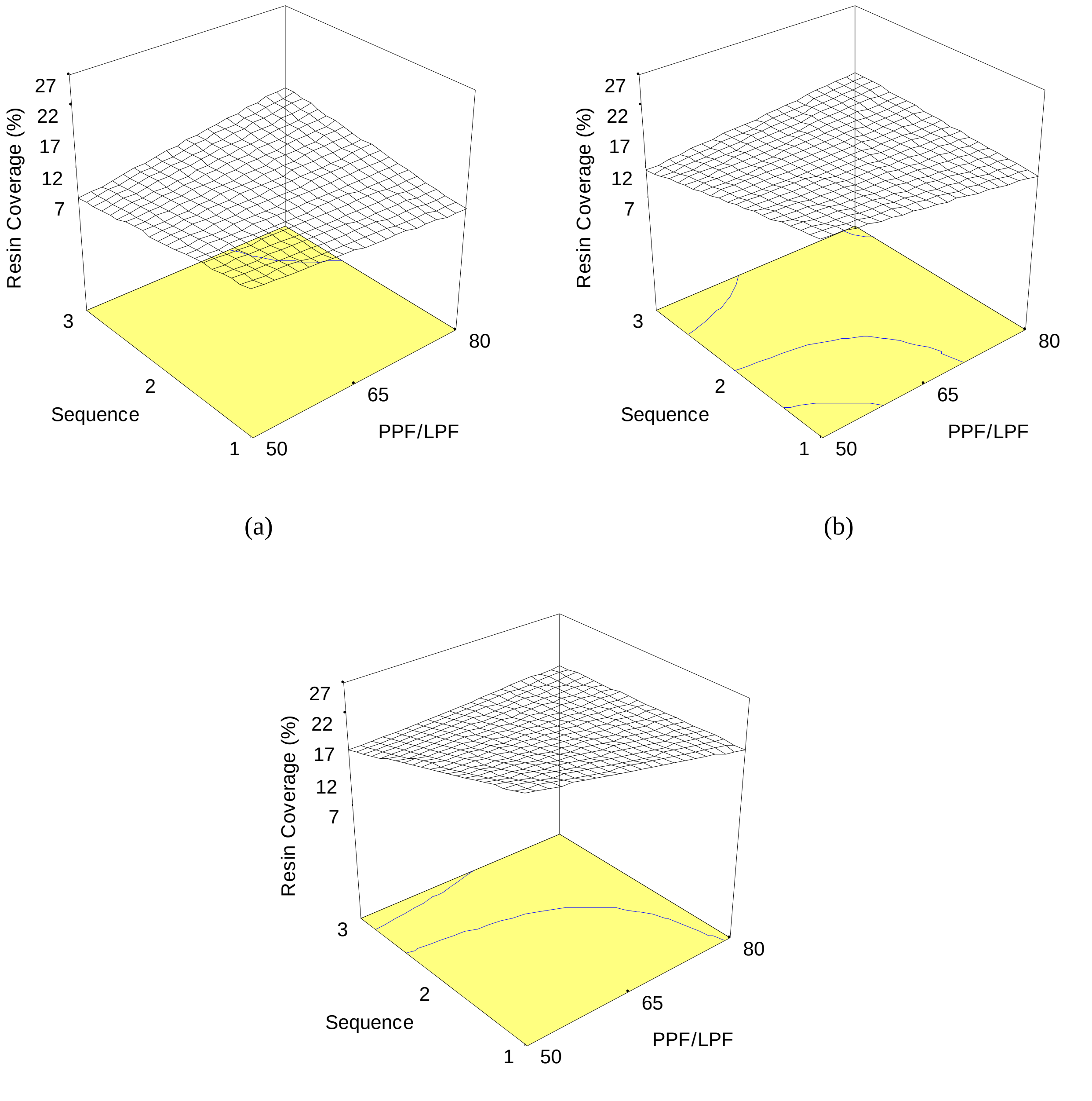


Figure 25 Resin coverage as influenced by resin application sequence, powder/liquid ratio, and resin content (the -1, 0, and +1 on the x-axis of the perturbation plot represent the lowest, middle, and highest level of each variable, respectively)



(a)

(b)

(c)

Figure 26 Resin coverage as influenced by the interaction of resin application sequence and powder/liquid ratio at different resin contents: (a) 3.0%, (b) 5.5%, and (c) 8.0%

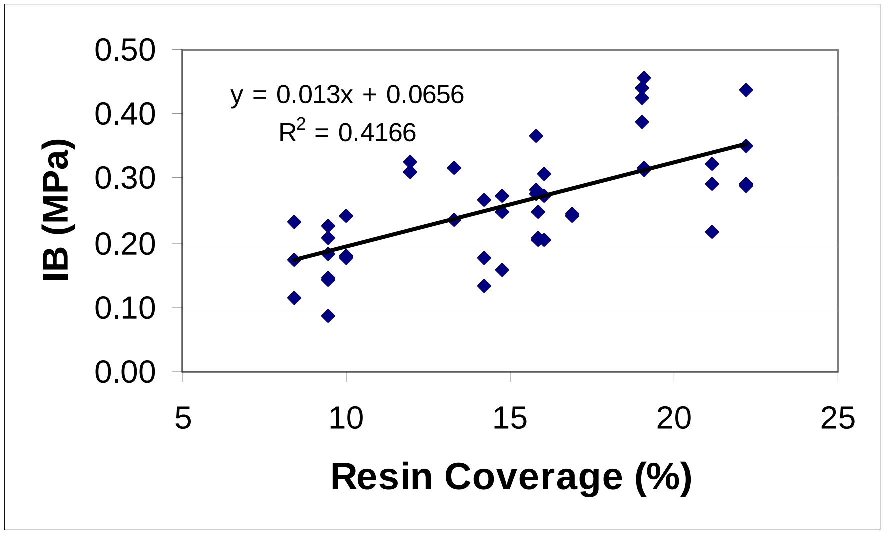


Figure 27 Internal bond strength of panel as a function of resin coverage

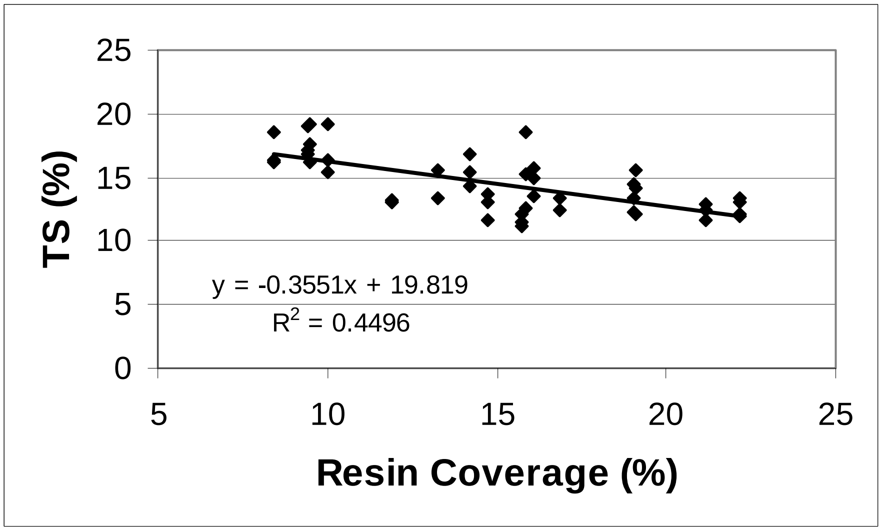


Figure 28 Thickness swelling of panel as a function of resin coverage

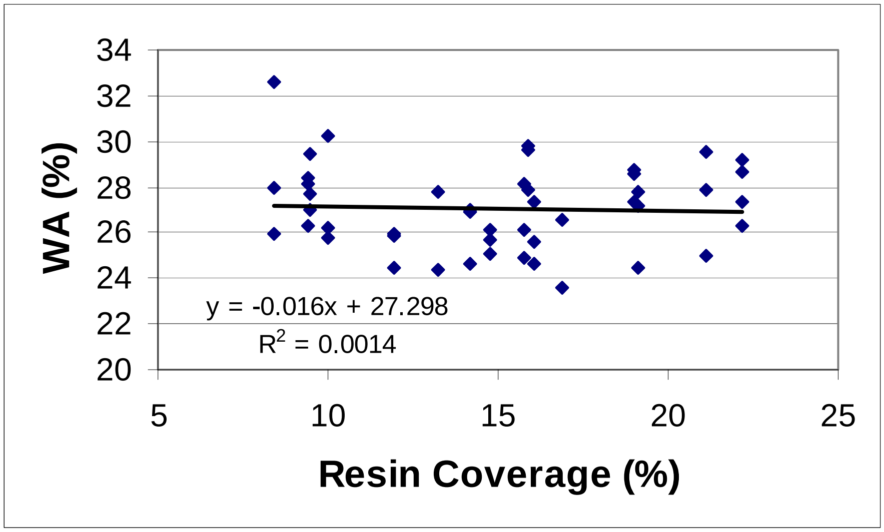


Figure 29 Water absorption of panel as a function of resin coverage

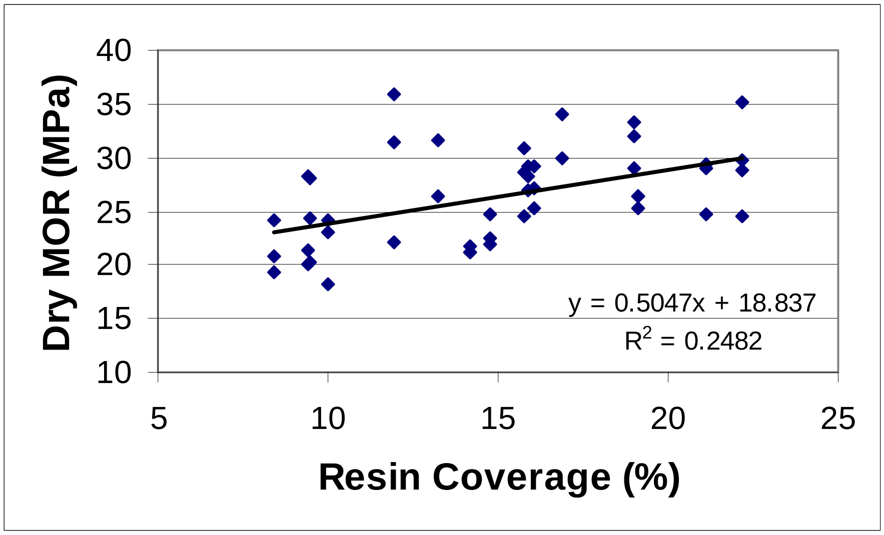


Figure 30 Dry modulus of rupture of panel as a function of resin coverage

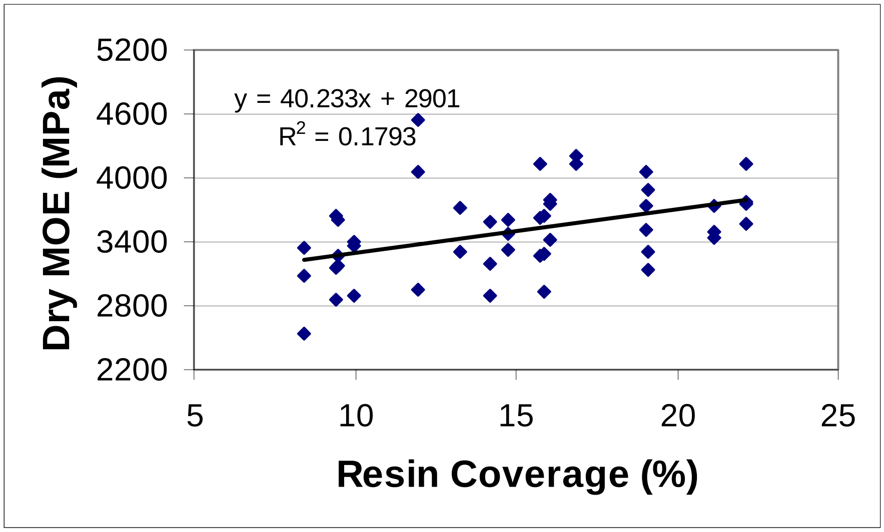


Figure 31 Dry modulus of elasticity of panel as a function of resin coverage

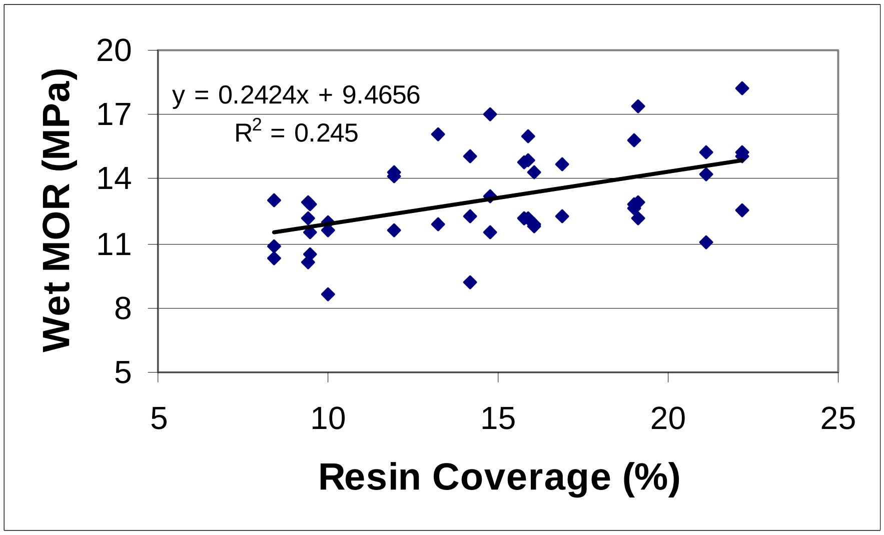


Figure 32 Wet modulus of rupture of panel as a function of resin coverage

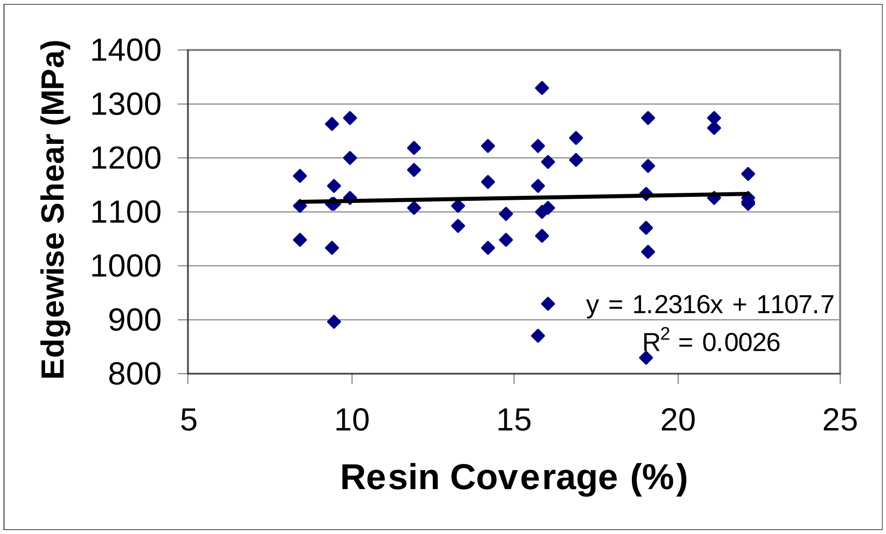


Figure 33 Edgewise shear strength of panel as a function of resin coverage

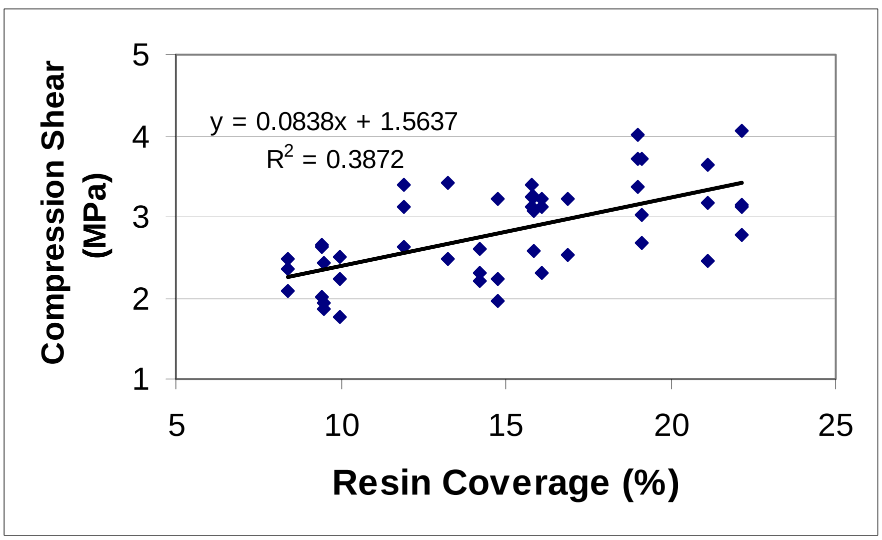


Figure 34 Compression shear strength of panel as a function of resin coverage

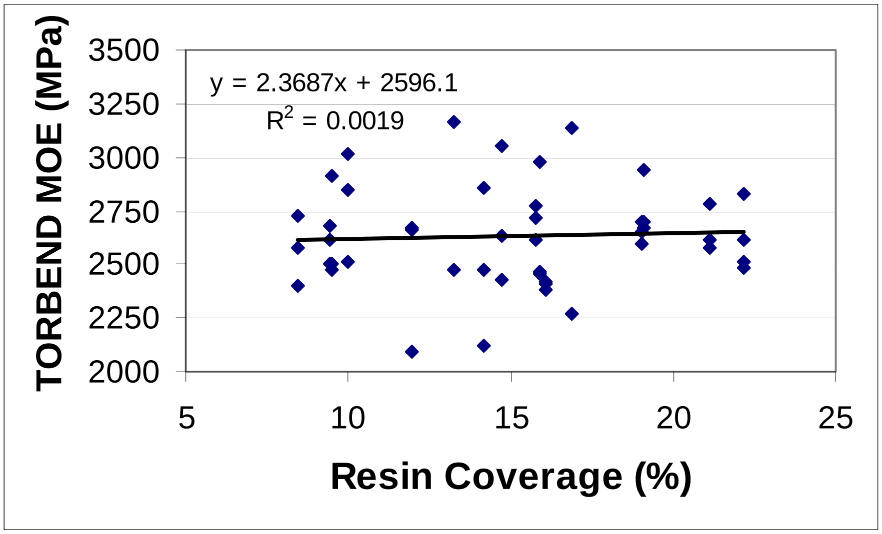


Figure 35 Modulus of elasticity of panel (measured by TORBEND method) as a function of resin coverage

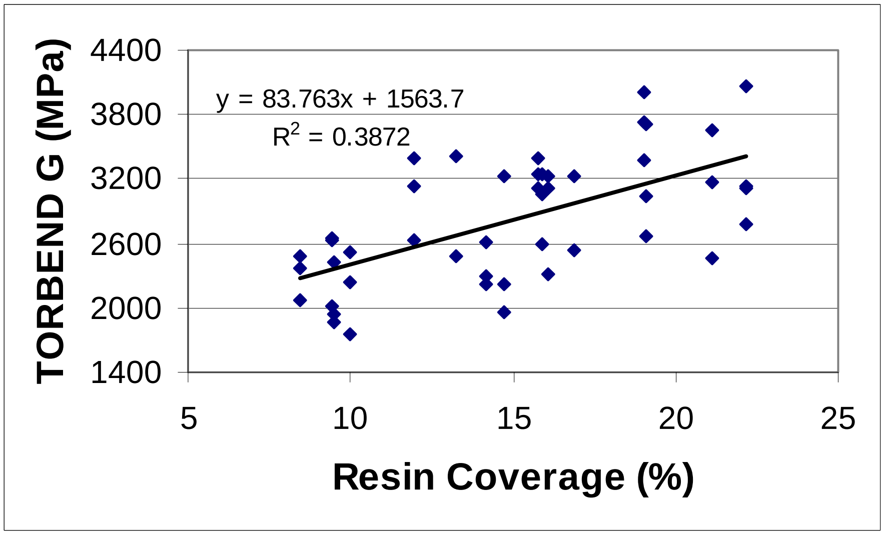


Figure 36 Shear modulus of elasticity of panel (measured by TORBEND method) as a function of resin coverage

7 Conclusions

The influence of resin content (3.0%, 5.5%, 8.0%), powder/liquid ratio (50:50, 65:35, 80:20), and application sequence (LPF-PPF-LPF, LPF-PPF, PPF-LPF) on strand board performance was investigated in this study. The main findings can be summarized as follows:

1. A number of response surface models were established to predict individual panel properties. Resin content is a significant model term for IB, TS, dry MOR and MOE, wet MOR, and compression shear properties. An increase in resin content improves these board properties regardless of resin application sequence or powder/liquid ratio.

2. Powder/liquid ratio is also a significant model term for TS, WA, and wet MOR. In general, the ratios around the middle level (65:35) improve TS and WA, while a decrease in the ratio improves wet MOR in each resin content and application sequence.

3. Resin application sequence is not a significant model term for all panel properties, but its interaction with resin content is the most significant model term for edgewise shear strength. In this case, the liquid-powder-liquid sequence combined with the lower level of resin content (3.0%) seemed to result in higher edgewise shear property compared with the other combinations.

4. Linear regression fitting indicates that the strongest correlation exists between IB and compression shear (R^2=0.70). TORBEND G seems to correlate to TORBEND MOE (R^2=0.40). In addition, TORBEND G also appears to correlate to compression shear (R^2=0.28) and IB (R^2=0.26). However, no correlation exists between static MOE and TORBEND MOE.

5. An increase in resin content significantly increases resin coverage on strand surfaces, as shown by an image analysis. The resin coverage increased with decreasing PPF/LPF ratio in sequence 1 (LPF-PPF-LPF), while it increased with increasing PPF/LPF ratio in sequence 3 (PPF-LPF).

6. In general, correlations of resin coverage with panel properties indicate that an increase in resin coverage improves TS (R^2=0.45), IB (R^2=0.42), compression shear (R^2=0.39), TORBEND G (R^2=0.39), dry MOR (R^2=0.25), wet MOR (R^2=0.25), and dry MOE (R^2=0.18). However, the resin coverage does not seem to correlate to WA, TORBEND MOE, or edgewise shear properties.

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