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ULTRA STIFF WOOD COMPOSITE: A COMPARISON OF STRENGTH PROPERTIES AGAINST EXISTING PRODUCTS IN THE FOREST PRODUCTS MARKET

By

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This investigation focuses on the production, strength properties, and marketability of a new ultra stiff wood composite. The basis of the examination is to compare strength properties such as, Modulus of Rupture, Modulus of Elasticity, Work to Max Load, and Density with currently available products.

The final analysis of the ultra stiff product suggested that this product would compete favorably in today's market due to the strength properties of the product. Although the current hot-pressing method is not economical for mass production, other ways of pressing can be utilized. It is noted in this research that the wood moisture content can influence MOE, MOR, and density properties. By manipulating and controlling the press cycle and the moisture content, a competitive product was produced.

Key words: Ultra Stiff Wood Composite, Modulus of Elasticity, Modulus of Rupture, Density, Moisture Content

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CHAPTER I

INTRODUCTION

Engineered wood products (EWP) have increasingly attracted attention and have consistently gained market share since their introduction. The opportunity for growth has generated much of the interest in these products. Investors are challenged to develop new products to reduce the cost of previously made products such as laminated veneer lumber (LVL), laminated strand lumber (LSL), parallel strand lumber (PSL), and oriented strand lumber (OSL). With new technologies, new methods are being developed to effectively and efficiently utilize smaller, faster growing, and lower quality trees to make high performance products. The engineered lumber method offers more stability, strength, and uniformity than conventional lumber and is comparable in cost. Despite the increasing volume of standing timber, much of this timber is second and third growth. Generally, these trees are less stable and have lower strength values due to a higher proportion of juvenile wood.

EWP have grown steadily since their introduction over 30 years ago and have continued to grow in the face of the raw materials shortages of the 1990s and the extreme low levels of competitive lumber prices since the turn of the century. EWP have attracted interest in recent years for several reasons. First, there is an expectation based on past performance that these products will continue to grow in market share and volume. Second, the past performance of leaders has suggested this to be a business with attractive returns. Third, some wood products companies look to diversify due to persistent over supply of traditional commodity-type wood products.

Economic realities of 2009 and the housing market has forced many companies begin layoffs and close mills. The number of engineered wood products mills in North America from 2006 to 2008 has fallen from 84 to 74, respectively (Spelter). Many mills have shut production lines down that tend to make lower density or lower stiffness (MOE) grade boards. These products just cannot compete with other higher density or higher MOE boards on strength versus cost. Several companies are trying to establish new ways to put novel competitive products on the market. This product described herein should be able to compete in this market.

This study focuses on the development of a new product, based off of the TimTek® process, which excels in the mechanical properties of engineered lumber and could compete economically with products on the market today. This high density wood composite product will produce high strength products from smaller, lower quality, and once undesirable trees. The objectives of this discussion are to determine if a change in moisture content and/or press schedules has an effect on the overall density and final strength properties of this high-density board. The process begins with a very low initial wood moisture content to see if a facilitate bonding between the scrim and resin. Then the initial furnish moisture content was increased to determine how much moisture the board can hold until steam is produced and the scrim-resin bonds blow apart. After the optimal initial moisture content has been obtained, a varying press schedules were used to determine if the press cycles can have an effect on the density and final strength properties of the product.

CHAPTER II

LITERATURE REVIEW

There are several currently available products on the market that are not doing very well due to the decline in construction markets. The construction market is the key driver for EWP (Schuler). Due to the cost of timber and production cost, this is becoming a problem for the Forest Products Industry. Ultra stiff wood products, the product produced in this study, is designed to use wood from once undesired wood materials to make a product that will not only be affordable to make but will also be stronger than other materials on the market.

USW produced during this experiment should be used for structural applications such as beams, headers, and column applications. This product consists of strands of wood, produced by the TimTek® process, bonded together by using a phenol-formaldehyde resin. The produce is evaluated per ASTM D 5456. The production methods developed at Mississippi State University for TimTek® process specify the certain production parameters such as scrim quality, resin formulation, resin content, lay-up procedures, pressing parameters, and post press quality inspection processes.

Table 2.1. Ultra Stiff Strength Properties

Type of Stresses	Allowable Stress		
	2.0E	2.2E	2.4E
Modulus of Elasticity (MOE)	1,994,188 psi	2,273,661 psi	2,439,575 psi
Edgewise flex stress MOR (F_b)	10,716 psi	11,744 psi	13,131 psi
Maximum Flexure	765	778	920
Work To Max Load (lbs-in/in ^3)	3.49	3.72	4.25
Calculated Density (lbs/ft^3)	59	60	62

Louisiana-Pacific Corporation markets a product called LP SolidStart strand lumber (LSL) that is lower in stiffness and strength than to this product. This product is used for structural applications, such as (beams, headers, joists, rafters and columns). The LP SolidStart LSL complies with the requirements noted in Section 2303.1.9 of the International Building Code (IBC). This product may also be used in structures regulated under the International Residential Code (IRC).

LP SolidStart LSL consists of wood stands bonded together using an exterior-type structural adhesive. The wood strand properties and species, adhesives, manufacturing parameters, and finished product dimensions and tolerances are as specified in the approved quality documentation and manufacturing standard (ICCES Louisiana Pacific 2403).

Table 2.2. LP LSL Strength Properties (ICCES Louisiana Pacific ESR-2403 Table 1)

Grade	Moe[4] ($x10^6$psi)	Beam Orientation		
		Bending[5] F_b (psi)	Shear F_v (psi)	Compression Perp-to-grain $F_{c\perp}$ (psi)
1730F_b^- 1.35E	1.35	1730	410	750
2360F_b^- 1.55E	1.55	2360	410	875
2640F_b^- 1.75E	1.75	2640	410	950

Louisiana-Pacific Corporation also has a product called LP SolidStart LVL. This product is made up of layers or wood veneers laminated together using an exterior-type structural adhesive. LP SolidStart LVL "Billet Beams" are fabricated by face laminating primary thicknesses together. This product is intended for structural applications: (beams, headers, joists, rafters, columns, rim boards, and wall studs.)

LP SolidStart LVL is an alternative to the other engineered materials described in Chapter 23 of the UBC. The SolidStart product complies with the requirements noted in Section 2303.1.9 of the IBC. The wood veneer properties and species, adhesives, manufacturing parameters, and finished product thickness, width and length must meet the requirements noted by the manufacturing standard (ICCES Louisiana Pacific ESR 1254).

Table 2.3. LP LVL Strength Properties (ICCES Louisiana Pacific ESR-1254 Table 1)

Grade	Moe ($x10^6$) Beam	Joist/Beam (Edge Loading)				
		F_b (psi)	F_t^3 (psi)	$F_{c\parallel}$ (psi)	$F_{c\perp}$	F_v
$1400F_b$-1.1E	1.1	1400	1200	1700	680	250
$1650F_b$-1.3E	1.3	1650	1200	1700	680	250
$1750F_b$-1.3E	1.3	1750	1200	1700	680	250
$2000F_b$-1.3E	1.3	2000	1200	2350	680	250
$2250F_b$-1.5E	1.4	2250	1350	2650	750	285
$2400F_b$-1.7E	1.7	2400	1350	2350	750	285
$2600F_b$-1.7E	1.7	2600	1350	2350	750	285
$2250F_b$-1.8E	1.8	2250	1600	2350	750	285
$2650F_b$-1.8E	1.8	2650	1600	2350	550	285
$2750F_b$-1.8E	1.8	2450	1600	2350	750	285
$2650F_b$-1.9E	1.8	2650	1600	2350	750	285
$2850F_b$-2.0E	2.0	2850	1800	3200	750	290
$2950F_b$-2.0E	2.0	2950	1800	3200	750	290
$3100F_b$-2.0E	2.0	3100	1800	3200	750	290
$3400F_b$-2.1E	2.1	3400	1800	3350	750	350
$3200F_b$-2.2E	2.2	3200	1800	2950	750	285

Weyerhaeuser has three structural composite lumber products that are comparable to this product. These products are used as alternatives to sawn lumber. These structural applications include use as (beams, headers, joists, rafters, columns, wall studs, and rim boards).

The first Weyerhaeuser product is TimberStrand laminated strand lumber (LSL). It is manufactured from strands of a single wood species or a combination of wood species blended with isocyanate based adhesives. TimberStrand LSL is produced with the wood strands oriented in a direction parallel to the length of the structural composite lumber, and has lengths up to 64 feet, thicknesses up to 5½ inches, and depths up to 48 inches (ICCES Weyerhaeuser ESR-1387).

Table 2.4. TimberStrand LSL Strength Properties (ICCES Weyerhaeuser ESR-1387 Table 1)

Grade Moe ($x10^6$)	Joist/Beam (Edge Loading)		
	F_b[6,7]	F_v	$F_{c\perp}$[8]
1.3	1700	400	680
1.5	2250	400	775
1.55	2325	400	800
1.6	2400	400	825
1.7	2600	400	880
1.9	3075	400	880
2.1	3500	400	880

The second product produced by Weyerhaeuser is Parallam parallel strand lumber (PSL). It is manufactured from stands of a single wood species, or species combinations, which are oriented parallel to the length of the member and coated with a phenol-formaldehyde adhesive. The wood species or species combinations and the adhesives used are specified in the manufacturing manual by Weyerhaeuser. Parallam (PSL) is available in rectangular cross sections having a maximum width of 11 inches, maximum depth of 19 inches, and length up to 66 feet (ICCES Weyerhaeuser ESR-1387).

Table 2.5. Parallam PSL Strength Properties (ICCES Weyerhaeuser ESR-1387 Table 4)

Species/Grade Southern Pine	Moe (x10^6)	Joist/Beam (Edge Loading)		
		F_b[5,6]	F_v	$F_{c\perp}$[7]
1.8E	1.8	2500	230	600
1.9E	1.9	2700	260	675
2.0E	2.0	2900	290	750
2.1E	2.1	3100	320	825

The third product produced by Weyerhaeuser is Microllam laminated veneer lumber (LVL). This product is manufactured from veneers of a single wood species, or species combinations of adhesives meeting requirements stated in the manufacturing manual by Weyerhaeuser. This product is produced by placing the veneers in a continuous feed press, with all the grain oriented parallel to the length of the member, and the veneers are bonded together with the approved adhesives. Microllam LVL is available in thickness of ¾ inch to 3½ inches, depth from 2½ inches to 48 inches, and length up to 80 feet (ICCES Weyerhaeuser ESR-1387).

Table 2.6. Microllam LVL Strength Properties (ICCES Weyerhaeuser ESR-1387 Table 5)

Billet Material Thickness	Grade/ Species	Moe (x10^6)	Joist/Beam (Edge Loading)		
			F_b[5,6]	F_v[7]	$F_{c\perp}$[8]
¾ inch To 3½	1.8 SP	1.8	2445	285	880
	1.9 SP	1.9	2600	285	880
	2.0 SP	2.0	2720	285	880
	2.2 SP	2.2	3060	285	880
	2.4 SP	2.4	3365	285	880
	2.6 SP	2.6	3675	285	880

Ainsworth Lumber Company produces four products that are used as alternatives to sawn lumber. These structural applications include use such as rim board, beams, headers, joists, and rafters. The four products are 1.7E Durastrand laminated strand lumber (LSL), 1.5E Durastrand oriented strand lumber (OSL), 1.3 Durastrand (OSL), and 0.8E Durastrand (OSL).

Durastrand is a structural composite lumber product composed of wood strands bonded together utilizing heat, pressure, and adhesives. Durastrand consists of three layers: two face layers having strands oriented in the longitudinal direction of the member and a core with strands oriented in the same plane perpendicular or parallel to the face layers. Durastrand is manufactured from strands of a combination of wood species including aspen, lodgepole pine, and birch. During fabrication, the stands are dried, resinated with adhesives having bond durability complying with ASTM D 5456 for Exposure 1 conditions, and formed into loose mats with three oriented layers. The quality control manuals specify the certain production parameters such as flake quality, flake grading, resin formulation, resin content, lay-up procedures, pressing parameters, and quality control issues. This product is available in depth up to 24 inches and length up to 48 feet for 1.7E (LSL), 1.5E (OSL), and1.3E (OSL). The 0.8E OSL is available in depth up to 24 inches and length up to 24 feet (ICCES Ainsworth ESR-1053).

Table 2.7. Durastrand Strength Properties (ICCES Ainsworth ESR-1053 Table 1)

Grade	Moe ($x10^6$)	Joist/Beam (Edge Loading)		
		F_b[3,4]	F_v	$F_{c\perp}$[7]
1.7E	1.7	2,150	400	1,200
1.5E	1.5	1,775	400	1,150
1.3E	1.3	1,625	350	1,150
0.8E	0.8	1,130	355	1,415

Pacific Woodtech Corporation and Georgia-Pacific have a product called G-P Lam (LVL). This product is a structural composite lumber consisting of laminated Douglas fir veneers with grain parallel to the face of the member. An exterior-type phenol-formaldehyde adhesive, complying with the durability requirements of ASTM D 2559, is used in the manufacture of the LVL, to bond the veneers in the lay up pattern specified in their quality control manual. This product is available in thickness ranging from ¾ inch to 3½, depth from 1¾ to 24 inches, and length up to 66½ feet. Two grades of LVL are recognized in this report: 1.8E and 2.0E LVL (ICCES Pacific ER-5598).

Table 2.8. G-P Lam LVL Strength Properties (ICCES Pacific ER-5598 Table 1)

Type of Stresses	Allowable Stress	
	1.8E LVL Grade	2.0E LVL Grade
Modulus of Elasticity (MOE)	1,800,000 psi	2,000,000 psi
Edgewise flex stress (F_b)[1,2,3,4]	2750 psi	3,100 psi
Horizontal shear (F_v)[4]	285 psi	285 psi
Compression Perp to grain (F_c)	850 psi	850 psi
Compression Parallel to grain (F_c)	2,300 psi	2,750 psi
Tensile strength (F_t)	1,950 psi	2,100 psi

Nelson Pine Industries also has a LVL product called NelsonPine LVL. This product is also intended for structural applications such as (beams, headers, joists, rafters, columns, and rim boards). NelsonPine LVL is structural composite lumber consisting of laminated radiata pine veneers with the grain parallel to the face of the member in a lay-up pattern specified in their quality control manual. An exterior-type phenol-formaldehyde adhesive, complying with ASTM D 2559, is used in the manufacture of the LVL, to bond the veneers. This product is available in thickness ranging from ¾ inch to 5¼ inches, depth from 1¾ inches to 16 inches, and length up to 80 feet. Two grades of LVL are recognized in this report: 1.3E and 1.5E LVL (ICCES Nelson ESR-1633).

Table 2.9. NelsonPine LVL Strength Properties (ICCES Nelson ESR-1633 Table 1)

Property (psi)	1.3E LVL Grade Joist	1.5E LVL Grade Joist
Modulus of Elasticity (MOE)	1,300,000 psi	1,500,000 psi
Edgewise flex stress MOR (F_b)[3]	2000 psi	2,300 psi
Longitudinal shear (F_v)[4]	300 psi	300 psi
Compression Perp to grain (F_c)	710 psi	710 psi
Compression Parallel to grain (F_c)	2,600 psi	2,800 psi
Tensile strength (F_t)	1,500 psi	1,700 psi

CHAPTER III

MATERIALS AND METHODS

The high density strand lumber in this study was produced from southern pine stock measuring 200mm or less in diameter. By using the patented technology, called TimTek®, logs were crushed in a set of crushing tolls and passed through a scrimming line producing scrim less than or equal to 6-mm thick and up to 2.4-m in length. After production, the scrim was dried in a kiln to a nominal 20% moisture content. Dried scrim was coated with a GP® 585D09 stage B resole phenol formaldehyde resin to yield a 20% resin solids and redried in a commercial conveyor dryer to 9% moisture content or less (Barnes 2006). A scrim collection box, as illustrated in Figure 3.1, was made out of 2x12's to the dimensions of the board 34"x 34". The amount of scrim used to get a 60 pound per cubic foot 34"x 34"x 1.75" board was determined by the formula of length x width x thickness / 1728 x 60, and the resultant calculation estimates that 70 pounds of scrim with resin are required to produce the desired density board. The scrim was hand-formed, cut to a length of 30"-34", and laid up in a 34"x 34"x12" box, as illustrated in Figure 3.2, so it could be placed into the Dieffenbacher Press (Fig.3.3).

Figure 3.1. 34”x34”x12” Box with Bottom caul Plate

Figure 3.2. Board Being Formed in Same Grain Direction

Figure 3.3. Dieffenbacher Press

During the course of this study, seven boards were produced and tested. Changes were made to the press cycle to improve strength properties after analysis of each board. The press cycles of each board, as illustrated in Figure 3.4, will be presented with the discussion of each pressed board. The test schedule and data was recorded by the Pressman program. By using the Pressman controls, the program was able to control and monitor the closing speed of the press and the pressure applied to the board, as illustrated in Figure 3.5. Once the board had been made, it was cut into samples measuring 20”x1”x final thickness of the board. The thickness varied between each board because the maximum pressure of the press was reached at 600 psi on the face of the board. The moisture content of the board along with the maximum pressure created slight differences in board thickness. Each board was cut into test specimens that were then tested for strength properties using an Instron testing machine with Bluehill software to control static bending tests.

SEG	CONTROL	SETPOINT	SEG. TIME	END CONDITION
1	PRESSURE	-52.2 psi/s	4 s	
2	POSITION	4.000 in.	5 s	
3	PRESSURE	75.0 psi	120 s	
4	PRESSURE	100.0 psi	180 s	
5	PRESSURE	150.0 psi	180 s	
6	PRESSURE	200.1 psi	240 s	
7	PRESSURE	250.0 psi	240 s	
8	PRESSURE	300.1 psi	240 s	
9	PRESSURE	300.1 psi	3276 s	COR TEMP >= 250.0 F
10	POSITION	1.750 in.	60 s	
11	POSITION	1.750 in.	3276 s	COR TEMP >= 280.0 F
12	POSITION	1.750 in.	240 s	COR TEMP >= 295.0 F
13	PRESSURE	100 psi	120 s	
14	PRESSURE	25.1 psi	120 s	
15	PRESSURE	0.0 psi	120 s	
16	POSITION	2.500 in.	60 s	
17	FASTPOSN	15.000 in.	15 s	

Figure 3.4. Sample Press Schedule for Pressman Controls

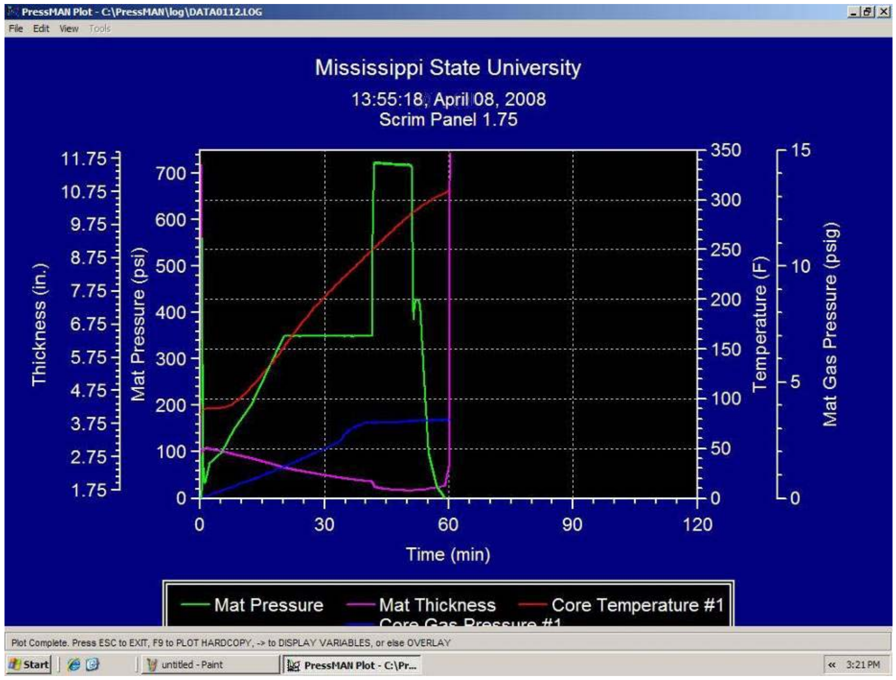

Figure 3.5. Pressman Screen Monitor

<u>Board 1</u>

During the process of making board one, it was started by collecting scrim produced by the TimTek® process. The scrim was placed onto drying trays and placed into the dryer. The temperature of the dryer was set to 80° C and the scrim was dried for 30 minutes. This scrim had a 20% resin solids before drying and about a 16% resin solids at time of the press cycle. A random sample was then taken from the scrim in the trays; this scrim was to be placed in another dryer for eight hours to determine final moisture content. This scrims' final moisture content came out to be 5%. The scrim was laid up in a 34"x 34"x 12" box with a caul plate (Fig.3.1) that was placed in the bottom with an additional non-stick additive added so the scrim would not stick to the plate. The amount of scrim used in the first board was 70 lbs of scrim with resin to produce a board with a density of 60 lbs per cubic foot. The scrim was laid up in the same grain direction, as illustrated in Figure 3.2, so that the maximum strength properties could be obtained. After the mat had been hand-formed, another caul plate with non-stick additive was placed on the top and the mat was placed into the press so the board could be produced, as illustrated in Figure 3.6. Although each board was carefully assembled in lay-up by hand for an even density across the face of the board, during the pressing operation scrim escaped or was squeezed out from each side of the board as the press closed because there were no side dams. Close examination of Figure 3.6 indicates that scrim has been forced out of the press on each side of the board being pressed. Squeeze out impacts the density profile across the face of the board. Essentially, each edge of the board is the lowest density and the density generally increases toward the center of the board. The schedule for the first press schedule is listed in Table 3.1. When the press cycle was finished, the board was removed from the press.

Figure 3.6 Scrim Material Being Pressed Into Board

Table 3.1 Board 1 Press Schedule

SEG	CONTROL	SETPOINT	SEG.TIME	END CONDITION
1	FASTPOSN	-0.300 in./s	4 s	
2	POSITION	50.00%	4 s	
3	POSITION	4.000 in.	10 s	
4	POSITION	3.750 in.	120 s	
5	POSITION	3.500 in.	180 s	
6	POSITION	3.250 in.	240 s	
7	POSITION	3.000 in.	300 s	
8	POSITION	2.750 in.	360 s	
9	POSITION	2.500 in.	420 s	COR TEMP>= 250.0 F
10	POSITION	2.250 in.	480 s	COR TEMP>= 260.0 F
11	POSITION	2.000 in.	480 s	COR TEMP>= 270.0 F
12	POSITION	1.750 in	540 s	COR TEMP>= 280.0 F
13	PRESSURE	0.0 psi	600 s	
14	POSITION	2.500 in.	60 s	
15	FASTPOSN	15.000 in.	10 s	

After the completion of board one, the impression of this board was not very good. Due to the press schedule, the press was opened prematurely and a good internal bond was not established.

Board 2

The process of making board two began by collecting scrim that was produced by the TimTek® process. During this experiment, the scrim was not put in the dryer. This scrim had a 20% resin solids at time of the press cycle. A random sample was then taken from the scrim in the trays; this scrim was to be placed in another dryer for eight hours to determine final moisture content. The final moisture content came out to be 9.0%. The scrim was laid up in a 34”x 34”x 12” box with a caul plate (Fig.3.1) that was placed in the bottom with an additional non–stick additive added so the scrim would not stick to the caul plate. The amount of scrim used in the second board was 70 lbs of scrim with resin to reach a density of 60 lbs per cubic foot. The scrim was laid up (Fig.3.2) in the same grain direction so that the maximum strength properties could be obtained. After the scrim had been laid up, the scrim was tied together with grass string such that less scrim would escape the press, another caul plate with a non-stick additive was placed on the top, and the mat was placed into the press so the board could be produced (Fig.3.6). During the second press cycle, illustrated in Table 3.2, the decision was made to make a schedule that relied on pressure instead of time.

Table 3.2 Board 2-5 Press Schedule

SEG	CONTROL	SETPOINT	SEG. TIME	END CONDITION
1	PRESSURE	-52.2 psi/s	4 s	
2	POSITION	4.000 in.	5 s	
3	PRESSURE	75.0 psi	120 s	
4	PRESSURE	100.0 psi	180 s	
5	PRESSURE	150.0 psi	180 s	
6	PRESSURE	200.1 psi	240 s	
7	PRESSURE	250.0 psi	240 s	
8	PRESSURE	300.1 psi	240 s	
9	PRESSURE	300.1 psi	3276 s	COR TEMP >= 250.0 F
10	POSITION	1.750 in.	60 s	
11	POSITION	1.750 in.	3276 s	COR TEMP >= 280.0 F
12	POSITION	1.750 in.	240 s	COR TEMP >= 295.0 F
13	PRESSURE	100 psi	120 s	
14	PRESSURE	25.1 psi	120 s	
15	PRESSURE	0.0 psi	120 s	
16	POSITION	2.500 in.	60 s	
17	FASTPOSN	15.000 in.	15 s	

After the completion of board two, a step was made in the right direction. The press schedule was changed to eliminate the premature opening. Board two had a slight blow (release of gas pressure thru the wood). This was caused by the moisture of the scrim before being pressed.

<u>Board 3</u>

During the process of making board three, it was started by collecting scrim produced by the TimTek® process. The scrim was placed onto drying trays and placed into the dryer. The temperature of the dryer was set to 80° C and the scrim was dried for 45 minutes. This scrim had a 20% resin solids before drying and approximately a 16% resin solids at time of the press cycle. A random sample was then taken from the scrim in the trays; this scrim was to be placed in another dryer for eight hours to determine final moisture content. The final moisture content was 4.0%. The scrim was laid up in a 34"x 34"x 12" box with a caul plate (Fig.3.1) that was placed in the bottom with an additional non-stick additive added so the scrim would not stick to it. The amount of scrim used in the third board was 68 lbs of scrim with resin to reach a density of 60 lbs per cubic foot. The scrim was laid up (Fig.3.2) in the same grain direction so that the maximum strength properties could be obtained. After the scrim had been laid up, the scrim was tied together with grass string so that less scrim would escape the press, another caul plate with non-stick additive was placed on the top, and the mat was placed into the press so the board could be produced (Fig.3.5). The same press schedule as illustrated in Table 3.2 was used to press this board.

The decision to use a lower initial moisture content and less scrim was made to keep the board from blowing. The same press schedule was used in this case, due to the fact that it closed properly in board two.

Board 4

During the process of making board four, it was started by collecting scrim produced by the TimTek® process. The scrim was placed onto drying trays and placed into the dryer. The temperature of the dryer was set to 80° C and the scrim was dried for 60 minutes. This scrim had a 20% resin solids before drying and about a 16% resin solids at time of the press cycle. A random sample was then taken from the scrim in the trays; this scrim was to be placed in another dryer for eight hours to determine final moisture content. The final moisture content came out to be 3.0%. The scrim was laid up in a 34”x 34”x 12” box with a caul plate (Fig.3.1) that was placed in the bottom with an additional non-stick additive added so the scrim would not stick to it. The amount of scrim used in the fourth board was 73 lbs with enough resin to reach a density of 63 lbs per cubic foot. The reason more scrim was used this time was to stretch the limits and try to produce a density of above 65 lbs per cubic foot in the center of the board. The scrim was laid up (Fig.3.2) in a parallel fashion such that the maximum strength properties could be obtained. After the scrim had been laid up, the scrim was tied together with grass string so that less scrim would escape the press, another caul plate with non-stick additive was placed on the top, and the mat was placed into the press so the board could be produced (Fig.3.6). The same press schedule, as illustrated in Table 3.2 for boards two and three, was also used to produce this board.

Board 5

During the process of making board five, the process was started by collecting scrim produced by the TimTek® process. Once the scrim was placed onto drying trays and placed into the dryer. The temperature of the dryer was set to 80° C and the scrim was dried for 30 minutes and checked for moisture and then dried some more so the target moisture of 6% could be obtained. This scrim had a 20% resin solids before drying and about a 16% resin solids at time of the press cycle. A random sample was then taken from the scrim in the trays; this scrim was to be placed in another dryer for eight hours to determine final moisture content. The final moisture content came out to be 5.7%. The scrim was laid up in a 34"x 34"x 12" box with a caul plate (Fig.3.1) that was placed in the bottom with an additional additive added so the scrim would not stick to it. The amount of scrim used in the fifth board was 70 lbs with resin to reach a density of 60 lbs per cubic foot. The scrim was laid up (Fig.3.2) in the same grain direction so that the maximum strength properties could be obtained. After the scrim had been laid up, the scrim was tied together with grass string so that less scrim would escape the press, another caul plate with additive was placed on the top, and the mat was placed into the press so the board could be produced (Fig.3.6). The same press schedule, as illustrated in Table 3.2, was also used to produce this board.

By using this process, the final thickness of 1.75 inches was still unable to be obtained, but the properties and glue bond were better than any other board. The final thickness reached 1.921 inches. The goal thickness could not be reached because the press did not have enough hydraulic pressure to close to 1.75 inches.

Board 6

During the process of making board six, the process was started out by collecting scrim produced by the TimTek® process. Once the scrim was placed onto drying trays and placed into the dryer. The temperature of the dryer was set to 80° C and the scrim was dried for 45 minutes. This scrim had a 20% resin solids before drying and about a 16% resin solids at time of the press cycle. A random sample was then taken from the scrim in the trays; this scrim was to be placed in another dryer for eight hours to determine final moisture content. The final moisture content came out to be 7.4%. The reason a higher moisture content was employed was so that a better bond and final thickness could be obtained. The scrim was laid up in a 34"x 34"x 12" box with a caul plate (Fig.3.1) that was placed in the bottom with an additional non-stick additive added so the scrim would not stick to it. The amount of scrim used in the first board was 70 lbs of scrim with resin to reach a density of 60 lbs per cubic foot. The scrim was laid up (Fig.3.2) in the same grain direction so that the maximum strength properties could be obtained. After the scrim had been laid up, the scrim was tied together with grass string so that less scrim would escape the press, another caul plate with non-stick additive was placed on the top, and the mat was placed into the press so the board could be produced (Fig.3.6). A new press schedule, illustrated in Table 3.3, was designed so that the press would close slower at the beginning. The reason for the slower closing time was to decrease the amount of damage to the scrim.

Table 3.3 Board 6 Press Schedule

SEG	CONTROL	SETPOINT	SEG.TIME	END CONDITION
1	PRESSURE	-52.2 psi/s	4 s	
2	POSITION	8.000 in.	5 s	
3	PRESSURE	75.0 psi	120 s	
4	PRESSURE	100.0 psi	180 s	
5	PRESSURE	150.0 psi	180 s	
6	PRESSURE	200.1 psi	240 s	
7	PRESSURE	275.0 psi	240 s	
8	PRESSURE	350.0 psi	240 s	
9	PRESSURE	350.0 psi	3276 s	COR TEMP >= 250.0 F
10	POSITION	1.750 in.	60 s	
11	POSITION	1.750 in.	3276 s	COR TEMP >= 280.0 F
12	POSITION	1.750 in.	240 s	COR TEMP >= 295.0 F
13	PRESSURE	100 psi	120 s	
14	PRESSURE	25.1 psi	120 s	
15	PRESSURE	0.0 psi	120 s	
16	POSITION	2.500 in.	60 s	
17	FASTPOSN	15.000 in.	15 s	

Board 7

During the process of making board seven, the process was started out by collecting scrim produced by the TimTek® process. Once the scrim was placed onto drying trays and placed into the dryer. The temperature of the dryer was set to 80° C and the scrim was dried for 45 minutes. This scrim had a 20% resin solids before drying and about a 16% resin solids at time of the press cycle. Since the last board was a success, the process was repeated, but the scrim had been air dried more and the moisture content going into the press was slightly lower. A random sample was then taken from the scrim in the trays; this scrim was to be placed in another dryer for eight hours to determine final moisture content. The final moisture content came out to be 6.3%. The scrim was laid up in a 34”x 34”x 12” box with a caul plate (Fig.3.1) that was placed in the bottom with an additional non-stick additive added so the scrim would not stick to it. The amount of scrim used in the first board was 70 lbs with sufficient resin to reach a density of 60 lbs per cubic foot. The scrim was laid up (Fig.3.2) in the same grain direction so that the maximum strength properties could be obtained. After the scrim had been laid up, the scrim was tied together with grass string so that less scrim would escape the press, another caul plate with non-stick additive was placed on the top, and the mat was placed into the press so the board could be produced (Fig.3.6). A new press schedule, illustrated in Table 3.4, was designed since the previous press schedule did not close as planned.

Figure 3.4 Board 7 Press Schedule

SEG	CONTROL	SETPOINT	SEG.TIME	END CONDITION
1	PRESSURE	-52.2 psi/s	4 s	
2	POSITION	12.000 in.	15 s	
3	PRESSURE	49.9 psi	120 s	
4	PRESSURE	100.0 psi	180 s	
5	PRESSURE	150.0 psi	180 s	
6	PRESSURE	200.1 psi	240 s	
7	PRESSURE	275.0 psi	240 s	
8	PRESSURE	350.0 psi	240 s	
9	PRESSURE	350.0 psi	3276 s	COR TEMP >= 250.0 F
10	POSITION	1.750 in.	60 s	
11	POSITION	1.750 in.	3276 s	COR TEMP >= 280.0 F
12	POSITION	1.750 in.	240 s	COR TEMP >= 295.0 F
13	PRESSURE	100 psi	120 s	
14	PRESSURE	25.1 psi	120 s	
15	PRESSURE	0.0 psi	120 s	
16	POSITION	2.500 in.	60 s	
17	FASTPOSN	15.000 in.	15 s	

CHAPTER IV

RESULTS AND DISCUSSION

The post press cut-up and testing process for each board was the same. The boards were removed from the press and sent to the wood shop where they were sawn. These sawn pieces were 1" in width x 1¾" in depth x 20" in length. The length was determined by complying with the ASTM D 4761-05 standards of span length (Fig.4.1).

Figure 4.1. awing Specimen to Length and Width

Each individual piece was then weighed in grams and then sent to the testing lab. The testing machine was set up and ran at a speed that complied with procedure 10.3 of the ASTM D 4761-05 standard. The test rate of speed shall be such that the sample target failure would be achieved in approximately 1 minute. The failure load should not be reached in less than 10 seconds nor more than 10 min (ASTM 4761). A span to depth ratio of 17:1 was used for all tests. The load head speed during the center point loading in bending test was .32 in./min. Each specimen was then loaded onto the machine and broken to determine the strength properties set up for the test such as: modulus of elasticity (MOE) (psi), modulus of rupture (MOR) (psi), maximum flexure (lbf), work to max load (lbs-in/in ^3), and calculated density (lbs/ft^3).

Board 1

During the process of board one, the press schedule (Table 3.1) and the making of the board was an experiment. The initial moisture content was 5%. The press schedule was not set right and the press kept opening and closing. Due to this human error, the internal bond quality between the resin and scrim was not very good. The final moisture content of the board was figured and came out to be 1%. The testing of the specimens was also an experiment. Each specimen was put on the testing platform in the parallel to grain direction (plank orientation). Once the test had been completed and the results were calculated, there were several decisions made to make the next board better: a change in press schedule, initial moisture content needed to be higher, and test the specimen in the perpendicular to grain direction (joist/beam orientation). The results of board one are listed below in Table 4.1.

Table 4.1 Test Results for Board One

Board	Specimen Name	Maximum Flexure load (lbf)	MOR (psi)	MOE (psi)	Work To Max Load (lbs-in/in ^3)	Calculated Density (lbs/ft^3)
1	1	480	3168	607692	1.18	54
1	2	507	3319	674917	1.13	56
1	3	665	4478	706566	2.22	59
1	4	694	4612	854407	1.58	59
1	5	477	3153	536121	1.11	59
1	6	636	4198	816969	2.22	59
1	7	572	3711	758550	1.49	57
1	8	478	3142	679665	1.16	58
1	9	535	3550	546077	2.2	59
1	10	635	4212	742216	1.53	59
1	11	330	2164	536115	0.78	58
1	12	510	3336	582227	1.48	58
1	13	519	3404	585296	2.28	57
1	14	493	3241	597280	1.85	57
1	15	442	3042	523757	1.68	53
Mean		531	3515	649857	1.59	58
C.O.V.		17.94	18.18	16.49	29.98	3.26
St. Dev.		95.3	639.14	107129.1	0.48	1.87
Minimum		330	2164	523757	0.78	53
Maximum		694	4612	854407	2.28	59

After looking at the results in Table 4.1, these values were not the values that were expected. The strength properties were low due to a few reasons. Obviously one reason is due to the press schedule; another reason was due to testing the samples in the wrong orientation.

Board 2

During the process of board two, the initial moisture content was changed to 9% and the press schedule (Table 3.2) was modified to close the press at a slower rate so that the goal thickness could be reached. Once this board came out of the press, the accumulation of gas pressure given off by the amount of moisture in the scrim was too much for the internal bond to handle and the bond blew. The specimen was still sent to the wood shop and then to testing. The final moisture content of this board came out to be 3%. Each specimen was then individually weighed, measured, tested in the joist/beam (Fig.4.2) orientation, and calculated. The results for board two are listed below in Table 4.2.

Figure 4.2. Specimen Being Tested in Joist/Beam Orientation.

After looking at the results of board two in Table 4.2, it appears that the change in press schedule and a higher moisture content allowed an internal bond to be established. Since an internal bond was established, it allowed the strength properties to be higher, but these properties were still not as strong as expected. The reason for the low strength properties in this board were due to the internal bond blowing.

Table 4.2 Test Results for Board Two

Board	Specimen Name	Maximum Flexure load (lbf)	MOR (psi)	MOE (psi)	Work To Max Load (lbs-in/in ^3)	Calculated Density (lbs/ft^3)
2	1	742	6893	1221206	2.31	54
2	2	839	7226	1303528	2.4	57
2	3	974	7988	1326640	3.11	58
2	4	904	6822	920572	3.19	57
2	5	466	3316	468936	2.45	56
2	6	863	6234	608227	3.97	58
2	7	856	5626	714344	3.77	59
2	8	778	5175	472828	4.22	60
2	9	731	4489	334987	3.78	55
2	10	629	3580	321305	2.92	53
2	11	438	2460	199559	3.34	53
2	12	656	3585	225982	4.18	53
2	13	728	4515	365693	3.68	59
2	14	762	5078	392344	4.07	60
2	15	986	6572	560272	5.3	59
2	16	653	4482	639839	1.83	60
2	17	674	4696	523610	3.03	59
2	18	688	4863	535981	2.75	58
2	19	799	5992	762532	2.99	57
2	20	1180	9084	960768	6.35	56
2	21	994	8177	1262921	3.3	54
2	22	1021	8952	1170181	4.46	53
Mean		789	5718	695103	3.52	57
C.O.V.		22.64	32.25	52.9	29.23	4.41
St. Dev.		178.69	1844.17	367717.6	1.03	2.51
Minimum		438	2460	199559	1.83	53
Maximum		1180	9084	1326640	6.35	60

Board 3

During the process of board three, the initial moisture content was changed to 4% and the press schedule (Table 3.2) was the same as board two, so the press would close at a slower rate and that the goal thickness could be reached. During this experiment, less scrim was used than previously to help prevent the bond from blowing. The final thickness was met but the density of the board wasn’t where it was expected due to escape of scrim from the press. The specimen was still sent to the wood shop and then to testing. The final moisture content of this board came out to be 1%. Each specimen was then individually weighed, measured, tested in the joist/beam (Fig.4.2) orientation, and calculated. The results of the testing for board three are listed in Table 4.3.

Table 4.3 Test Results for Board Three

Board	Specimen Name	Maximum Flexure load (lbf)	MOR (psi)	MOE (psi)	Work To Max Load (lbs-in/in ^3)	Calculated Density (lbs/ft^3)
3	1	614	5404	876694	2.77	43
3	2	675	5945	1086867	2.24	46
3	3	906	8429	1146603	4.21	50
3	4	982	9050	1205061	4.73	52
3	5	962	8747	1228047	4.05	55
3	6	1073	9665	1324525	4.41	55
3	7	1055	9315	1434969	3.57	55
3	8	1041	9491	1559028	3.32	59
3	9	1340	12092	1654966	5.15	61
3	10	1462	12951	1649770	7.28	58
3	11	1023	9352	1503247	3.59	61
3	12	1254	11069	1647406	4.37	61
3	13	1261	11110	1786623	5.02	63
3	14	1236	10958	1669582	4.19	61
3	15	958	8316	1430980	2.8	58
3	16	1277	11338	1618946	4.78	60
3	17	1273	11221	1592244	4.87	59
3	18	1230	11382	1608802	4.91	58
3	19	1001	8857	1532652	3.04	57
3	20	857	7664	1324121	2.64	55
3	21	775	6818	1221490	2.32	54
3	22	880	7684	1308740	2.85	52
3	23	644	10092	1775255	3.54	49
3	24	581	9197	1727352	2.98	49
3	25	546	8816	1673502	2.83	46
Mean		996	9399	1463499	3.86	55
C.O.V.		25.85	19.84	16.34	29.99	9.85
St. Dev.		257.55	1864.51	239120	1.16	5.42
Minimum		546	5404	876694	2.24	43
Maximum		1462	12951	1786623	7.28	63

Upon examining the results of board three, the MOR and density were extremely low on the sides of the board as compared to the middle. The reason for this was due to the escape of scrim material at the initial closure segment of the press. Once the scrim escaped, the sides of the board were not as dense as the middle, where the scrim did not escape. The average MOR increased on this board since the internal bond did not blow. The strength properties were still not as strong as expected because the initial moisture content was too low for a good internal bond to be established.

<u>Board 4</u>

During the process of board four, the initial moisture content was changed to 3% and the press schedule (Table 3.2) was the same as board two, so the press would close at a slower rate and that the goal thickness could be reached. During this experiment, the amount of scrim used in the fourth board was 73 lbs of scrim with resin to reach a density of 63 lbs per cubic foot. The reason more scrim was used this time was to stretch the limits and try to produce a density of above 65 lbs per cubic foot in the center of the board. The goal of density was reached, but the final thickness goal of 1.75 inches could not be obtained. The reason for this was because with the amount of scrim needed for a 65 lb board at a moisture content of 3% was too great and the press just couldn't press anymore. The internal bond on this board was not as high as anticipated, likely this was because there was not enough moisture in the scrim to bond the resin solids and the scrim together. Despite the relatively low IB, the specimen prepared as appropriate and mechanically tested. The final moisture content of this board came out to be <1%. Each specimen was then individually weighed, measured, tested in the joist/beam (Fig.4.2) orientation, and calculated. The results of the testing for board three are listed in Table 4.4.

After examining the results of board four, it was noticed that the thickness and initial moisture content could have affected the average MOR. The thickness of this board allowed the MOR to be slightly higher than board three. The initial moisture content was to low to establish enough moisture during the press cycle to establish an effective internal bond.

Table 4.4 Test Results for Board Four

Board	Specimen Name	Maximum Flexure load (lbf)	MOR (psi)	MOE (psi)	Work To Max Load (lbs-in/in ^3)	Calculated Density (lbs/ft^3)
4	1	447	6578	1763885	1.85	49
4	2	558	8010	1851983	2.14	53
4	3	550	7743	1832198	2.03	54
4	4	496	7577	1795172	2.02	55
4	5	671	9306	1894747	2.72	56
4	6	663	8952	1948041	2.65	56
4	7	739	9604	1987703	2.89	57
4	8	743	9839	2016317	2.77	58
4	9	767	10163	2147927	2.82	60
4	10	851	11281	2272518	3.38	61
4	11	747	9705	1941277	2.87	59
4	12	645	8353	1915665	2.09	58
4	13	668	8839	1925845	2.3	59
4	14	827	10946	2277316	3.08	62
4	15	777	10087	1941923	3.04	61
4	16	967	12491	2300095	3.93	61
4	17	997	12948	2504174	4.05	62
4	18	908	11955	2257380	3.84	60
4	19	913	12264	2562197	4.59	60
4	20	643	8476	2124610	1.97	56
4	21	576	7594	1789810	2.24	53
4	22	494	6513	1602627	1.83	50
Mean		711	9510	2029700	2.78	57
C.O.V.		22.03	19.73	12.16	28.19	6.42
St. Dev.		156.7	1876.59	246809.9	0.78	3.68
Minimum		447	6513	1602627	1.83	49
Maximum		997	12948	2562197	4.59	62

Board 5

During the process of board five, the initial moisture content was changed to 5.7% and the press schedule (Table 3.2) was the same as board two, so the press would close at a slower rate and that the goal thickness could be reached. The amount of scrim used in the fifth board was 70 with enough resin to reach a density of 60 lbs per cubic foot. The goal of density was reached, but the final thickness goal of 1.75 inches could not be obtained. The internal bond on this board was good this time, since there was enough moisture in the scrim to bond the resin solids and the scrim together. The specimen was sent to the wood shop and then to testing. The final moisture content of this board came out to be 2%. Each specimen was then individually weighed, measured, tested in the joist/beam (Fig.4.2) orientation, and calculated. The results of the testing for board three are listed in Table 4.5.

After examining the results of board five, higher MOR results were recorded, even though the target final thickness was not obtained. The initial moisture content of the board was higher and allowed enough moisture to be distributed thru the board to establish a better internal bond. The improved bond allowed both the MOR and MOE to be higher.

Table 4.5 Test Results for Board Five

Board	Specimen Name	Maximum Flexure load (lbf)	MOR (psi)	MOE (psi)	Work To Max Load (lbs-in/in ^3)	Calculated Density (lbs/ft^3)
5	1	476	7262	1774325	1.95	52
5	2	768	11033	2245105	3.53	57
5	3	765	11228	2127345	3.45	58
5	4	811	11570	1826936	4.37	58
5	5	691	10269	1937864	3.12	60
5	6	669	9378	1950572	2.58	60
5	7	1051	14622	2168504	6.13	62
5	8	800	11163	2014747	3.57	60
5	9	788	11030	2205020	3.38	62
5	10	889	11884	2150312	3.77	61
5	11	815	10837	1844314	3.78	60
5	12	836	11576	1833510	4.67	61
5	13	627	9085	1940745	2.47	63
5	14	690	9133	1998669	2.37	62
5	15	685	9536	1897224	3.17	62
5	16	1000	13577	2213736	4.86	62
5	17	963	12877	2112313	4.63	60
5	18	772	10920	2299433	3	61
5	19	732	10452	1866538	3.33	58
5	20	830	11519	1937899	4.1	57
5	21	643	8922	1802728	2.56	56
5	22	532	7883	1724289	2.04	53
Mean		765	10716	1994188	3.49	59
C.O.V.		18.19	16.3	8.52	29.2	4.81
St. Dev.		139.17	1747.12	169953.1	1.02	2.85
Minimum		476	7262	1724289	1.95	52
Maximum		1051	14622	2299433	6.13	63

Board 6

During the process of board six, the initial moisture content was changed to 7.4% and a new press schedule (Table 3.3). The amount of scrim used in the sixth board was 70 lbs with resin to reach a density of 60 lbs per cubic foot. The reason for higher moisture content was so that a better bond and final thickness could be obtained. The goal of density was reached, but the final thickness goal of 1.75 inches still could not be obtained. With the adjustment of segment two in the press schedule, the press was allowed to close with 75.0 psi from eight inches instead of four inches. This allowed the press to close those four inches at a slower rated as well as eliminated the escape of some of the scrim from the side of the press. The internal bond on this board was improved, likely because there was enough moisture in the scrim to bond the resin solids and the scrim together. The specimen was sent to the wood shop and then to testing. The final moisture content of this board came out to be 2.5%. Each specimen was then individually weighed, measured, tested in the joist/beam (Fig.4.2) orientation, and calculated. The results of the testing for board three are listed in Table 4.6.

After examining the results in board six, the MOR and MOE values were the best that had been produced during the study. Since the final thickness was still not reached, the reason for the success of this board had to be the initial moisture content. There was sufficient moisture in the board to establish good internal bond strength but not so much as to develop gas pressure to blow the glue bond. Although the new press schedule was used, it still did not close as slow at the beginning as intended.

Table 4.6 Test Results for Board Six

Board	Specimen Name	Maximum Flexure load (lbf)	MOR (psi)	MOE (psi)	Work To Max Load (lbs-in/in ^3)	Calculated Density (lbs/ft^3)
6	1	532	8301	1535270	3.26	47
6	2	516	8469	1820158	2.37	53
6	3	576	8953	1981838	2.45	56
6	4	621	9743	2192811	2.53	57
6	5	900	13535	2359327	5.09	60
6	6	791	12924	2877197	3.72	65
6	7	983	13919	2354913	5.3	61
6	8	904	13742	2469148	4.47	63
6	9	910	13758	2459067	4.55	64
6	10	935	13768	2298588	5	64
6	11	985	14147	2496164	4.61	63
6	12	881	12903	2426050	3.99	64
6	13	1072	15863	2696137	5.88	65
6	14	987	14776	2712976	4.63	65
6	15	838	12806	2406834	3.94	64
6	16	661	9783	2313159	2.37	62
6	17	848	12634	2318487	4.01	61
6	18	734	10935	2308481	2.96	61
6	19	769	11471	2269792	3.38	61
6	20	660	10001	2256152	2.52	60
6	21	818	12665	2425110	3.98	61
6	22	806	12292	2200378	4.31	59
6	23	557	8760	1862829	2.68	55
6	24	377	5715	1526988	1.3	49
Mean		778	11744	2273661	3.72	60
C.O.V.		23.12	21.38	14.55	30.75	8.3
St. Dev.		179.79	2511.36	330720.8	1.14	4.99
Minimum		377	5715	1526988	1.3	47
Maximum		1072	15863	2877197	5.88	65

Board 7

During the process of board seven, the initial moisture content was changed to 6.3% and a new press schedule (Table 3.4). The amount of scrim used in this board was 70 lbs with sufficient resin to reach a density of 60 lbs per cubic foot. The reason for higher moisture content was so that a better bond and final thickness could be obtained. The goal of density was reached, but the final thickness goal of 1.75 inches still could not be obtained. The internal bond on this board was good this time, since there was enough moisture in the scrim to bond the resin solids and the scrim together. The specimen was sent to the wood shop and then to testing. The final moisture content of this board came out to be 2.5%. Each specimen was then individually weighed, measured, tested in the joist/beam (Fig.4.2) orientation, and calculated. The results of the testing for board seven are listed in Table 4.7.

Table 4.7 Test Results for Board Seven.

Board	Specimen Name	Maximum Flexure load (lbf)	MOR (psi)	MOE (psi)	Work To Max Load (lbs-in/in ^3)	Calculated Density (lbs/ft^3)
7	1	677	10932	1974617	3.59	53
7	2	892	13253	2302212	4.64	57
7	3	771	11346	2209517	3.47	59
7	4	861	12654	2395468	3.9	61
7	5	826	12713	2438253	3.84	62
7	6	791	11514	2394176	3.29	63
7	7	984	13934	2344169	5	63
7	8	923	12995	2476297	3.88	66
7	9	1092	15375	2777679	4.92	67
7	10	1148	15761	2781252	5.15	66
7	11	1019	14190	2353432	5.06	66
7	12	929	13016	2520560	3.83	66
7	13	1007	13493	2565124	4.04	65
7	14	1120	15380	2722118	5.26	64
7	15	1122	15543	2662258	5.36	64
7	16	890	12339	2454418	3.53	65
7	17	940	13308	2537484	5.41	63
7	18	997	14182	2484490	4.74	62
7	19	856	12250	2411400	3.53	61
7	20	746	10724	2203500	3.44	60
7	21	735	10848	2222660	3.32	57
Mean		920	13131	2439575	4.25	62
C.O.V.		14.79	11.96	8.24	17.98	5.61
St. Dev.		136.15	1570.96	201004.9	0.76	3.5
Minimum		677	10724	1974617	3.29	53
Maximum		1148	15761	2781252	5.41	67

After examining the results of board seven, it appears that the new press schedule, that allowed the press to close slower at the beginning of the process, helped raise the strength property averages. Although the initial moisture content was slightly lower, the press closed slower and kept most of the scrim in the press instead of allowing it to escape via squeeze out at the beginning of the press cycle. Boards six and seven were the best boards produced during the study and were used to develop models to explain MOR and MOE as functions of density. Using the data from these two boards, density explains 67 % of the variation in MOR and it explains 83 % of the variation in MOE. A priori, the expectation would be that as density increases, strength and stiffness increase. The regression analysis confirms positive coefficients between density and both MOE and MOR. Further the model equations are highly significant with F values of 85.8 for MOR and 217.1 for MOE. Figure 4.3 shows the relationship that exists between the predicted and actual MOE values associated with the regression equation. The regression equation for MOE is as follows:

$$MOE = -1234822 + 58678 * Density$$

Figure 4.4 shows the predicted MOR versus actual MOR for the regression equation. The regression equation for MOR is as follows:

$$MOR = -12310.4 + 404.21 * Density$$

Both equations fit the data reasonably well given the natural variability in wood. Each equation contains an unexplained component or error term which could include many of the natural growth and strength characteristics of wood which is not a homogeneous material. Further efforts were made to determine if ranges of density (low, medium, and high) could be use as categories to indicate impacts on MOE and MOR. Results showed that there were no significant differences among the low and medium density sample groups but the high density group was significantly different. However, after examination of the number of samples in the low and medium group, it was decided not to report due to a lack of degrees of freedom.

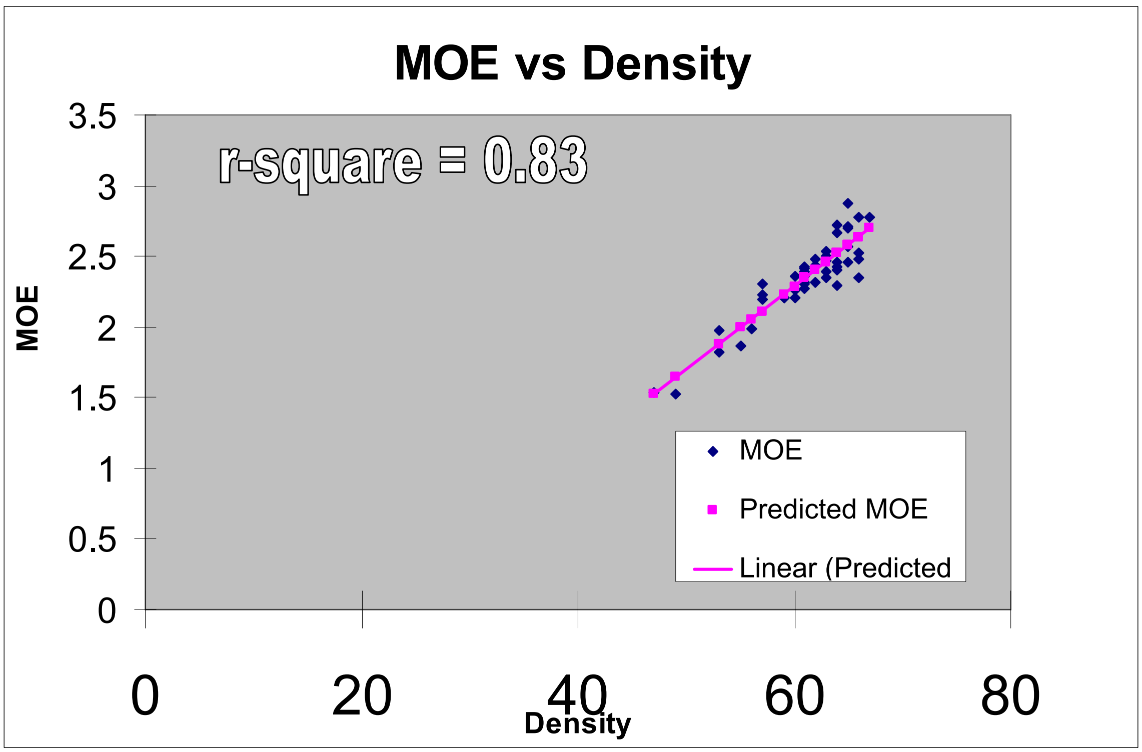

Figure 4.3 Actual MOE Plotted Against Predicted MOE From Regression Equation.

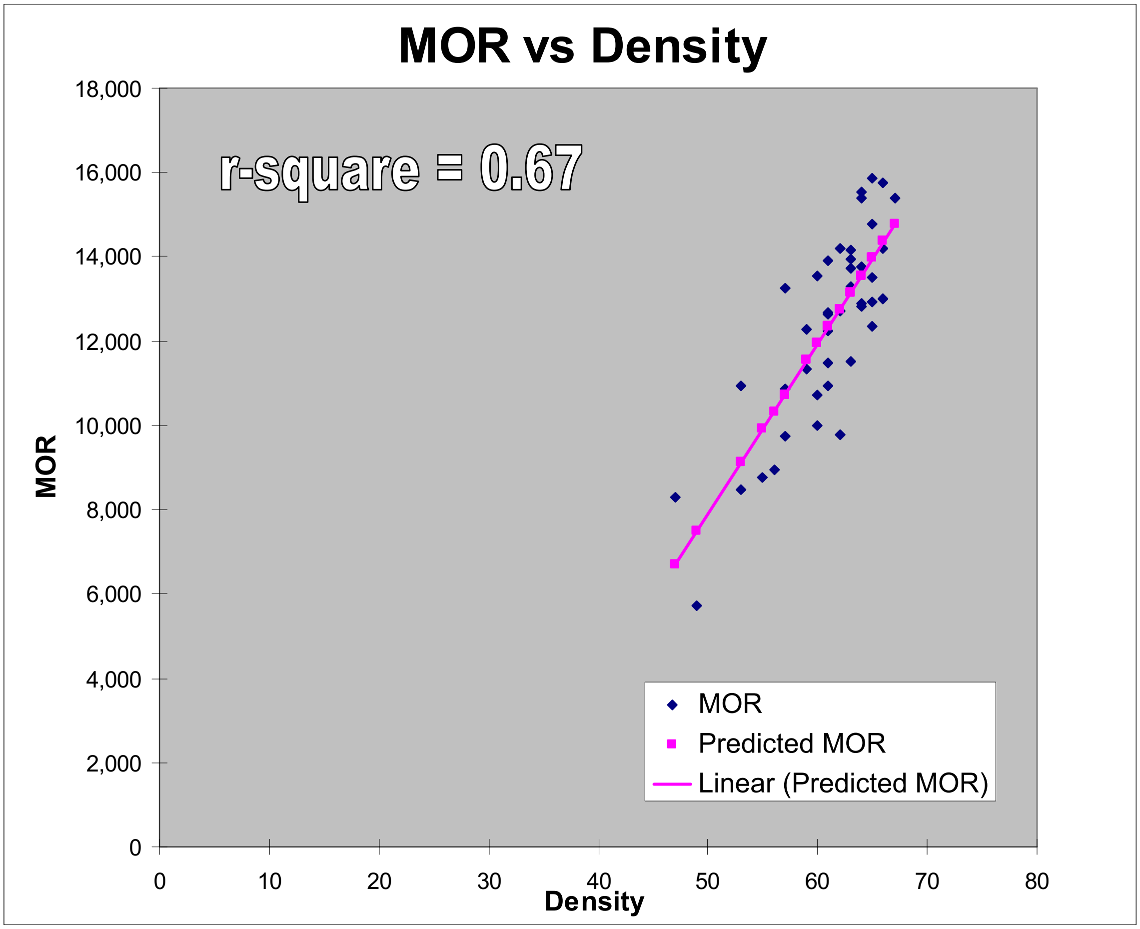

Figure 4.4 Actual MOR Plotted Against Predicted MOR From Regression Equation.

CHAPTER V

SUMMARY AND CONCLUSION

Reviewed literature indicated that there are many different types of engineered lumber products that compete with the product in this research. Each different product has its own special characteristics and properties. Due to the rising problems with the economy, the economic value is a vital part in each product. Comparisons in other studies that use similar materials and density should be made carefully and under the awareness that this study used a PF resin.

For the mechanical properties examined, the strength properties of the product made in this experiment are much greater than any other product on the market. The properties of this product could easily compete on the market today. A board that can produce these properties from low-end small diameter trees, that have little economic value, can be something that could help the timber market, as well as, the forest products industry.

Physical properties examined demonstrated that the moisture content is a major factor in making a successful and competitive board. The amount of moisture in the scrim must be high enough so the internal bond will procure, but low enough so that too much gas pressure will not build up. The amount of moisture also helps reach the final goal thickness. With a moisture content that is too low, so much scrim is needed to make the weight to produce a 60 lb board that the mat is initially too thick to actually press to the goal thickness of 1.75 in. only because of our 600 psi pressure limit, some presses can go higher.

Economic value of this board could be outstanding, due to the low-cost raw materials and the efficient process of producing the scrim. By using these low-end trees that have a very limited market, the cost of buying the material is minimal. The one downfall in this experiment was the length of press time. With a press time of the extreme length, the value of this board would be pretty high and not very competitive to other products. By using this process, it would not be very economical to produce this product; a steam injection process could be used to help with the economic value. This should be further studied but was beyond the scope of this study of determining what could be achieved.

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