ISOCYANATES (M.D.I.)
FP 2.2.1

ALBERTA RESEARCH COUNCIL
INDUSTRIAL TECHNOLOGIES DEPARTMENT
FOREST PRODUCTS PROGRAM[1]

1987

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DISCLAIMER

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SUMMARY

Binders significantly influence the cost and properties of wood composites such as waferboard and oriented strandboard (OSB). As isocyanate binders offer the advantages of fast cure time, curing at low temperature, acceptance of higher moisture content furnish and no formaldehyde emissions, their use in wood composites in place of traditional phenol formaldehyde (PF) resins warrants investigation.

The objective of this project was to determine the suitability of isocyanates for Alberta panel manufacture. Main elements of this project included:

1. state-of-the-art review

2. preliminary work to develop the capability to make panels using isocyanate binder in the ARC panel laboratory, and

3. manufacture and evaluation of 610 x 1220 mm strandboard panels using three levels of isocyanate binder and PF resin as control.

The panels made with isocyanate binder in the laboratory, using production schedules developed for PF panels, demonstrated equivalent or improved properties over those made with PF, for similar and, in some cases, for lower resin levels:

* thickness swell: isocyanates were much better
* modulus of elasticity: isocyanates were better
* modulus of rupture: isocyanates were better
* bond durability after two hour boil: showed no difference
* linear expansion: showed no difference, and
* internal bond: showed no difference.

Although further work is required to determine if isocyanates are a viable alternative to PF resins at this time for Alberta panel producers, there is no doubt that isocyanates are suitable for OSB/waferboard production and will likely become more accepted by industry.

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1. OBJECTIVES AND GOALS

The following objectives and goals for the year ended March 31, 1987 are as set out in Proposal for Basic 1986/87 Funding of the ARC Forest Products Program to the B.4 Canada/Alberta Forest Resource Development Agreement Committee. Document No. 86-PFP-8, March 10, 1986, and as agreed to by C/A FRDA.

Project #2.2: ALTERNATE ADHESIVES

Objective of the Project:

To determine suitability of alternate adhesives for Alberta panel manufacture.

Study #2.2.1: ISOCYANATES (M.D.I.)

Objective of this Study:

To determine the suitability of isocyanates for Alberta panel manufacture.

Goals for this Year:

Preliminary work to develop the capability to make panels using isocyanate binder and evaluate the panels.

2. INTRODUCTION

2.1 General

Isocyanates are highly reactive compounds whose potential as adhesives in panel products, especially structural panel products, has yet to be realized. The good strength properties, fast press time and tolerance to high moisture content furnish make isocyanates an obvious alternative to the more commonly used phenol formaldehyde (PF) based resins. It was under this premise that this study was undertaken.

The objective of this study was to determine the suitability of isocyanates for Alberta panel manufacture. To meet its objective, the Alberta Research Council (ARC) Forest Products Group needed to review the current technology, to develop the capability to make panels using isocyanate binder in their laboratory, and to produce and test a number of waferboard panels using isocyanate binder.

This report is submitted to the B.4 Committee Canada/Alberta Forest Resource Development Agreement (C/A FRDA) by the Forest Products Program, Industrial Technologies Department, Alberta Research Council. It covers the activities for the year 1986/1987 under Study #2.2.1: Isocyanates, but specifically focuses on the manufacture and evaluation of 610 x 1220 mm waferboard panels produced at ARC. The purpose in manufacturing these panels was to:

a) show that panels using isocyanate binder can be manufactured in the ARC laboratory;

b) obtain basic characteristics of isocyanate binder in panel production and;

c) compare properties of panels made from isocyanate binder to powder PF panels.

Because this study is at its infancy, it was not possible to investigate any of the advantages offered by isocyanates in manufacture, such as faster curing or curing at lower temperatures.

As a result, the planned scope of work for this year was to manufacture twelve panels using three resin levels of polymeric diphenylmethane diisocyanate (MDI) and compare them to five control panels using powder PF resin.

Because of potential health and handling hazards, some preliminary development work was required before panel manufacture could begin. Air-supplied respirators were supplied to all personnel. Ventilating equipment was installed above the blenders. Safety procedures were established.

2.2 Background

A contract was awarded Forintek Canada Corp. to conduct a state-of-the-art review on the current state of MDI technology in bonding wood composites. This report was designed to bring sufficient information to the fore so that the use of MDI might be seen as a more realistic alternative by industry.

The report, FPLC-2: Bonding Wood Composites with Isocyanates, P. R. Steiner, Forintek Canada Corp., Vancouver, June, 1986, was previously submitted to the Committee and is shown in Appendix H.

In summary, the report found that isocyanates are highly reactive compounds, which have been used for years in the plastics industry but which have only recently been considered for bonding wood composites, in particular particleboard. They offer the following advantages, compared with phenol formaldehyde resins:

* relatively rapid curing,
* curing at temperatures well below hot press temperature, as well as at hot press temperatures,
* tolerance to furnish with higher moisture content, and
* no formaldehyde emissions.

The following disadvantages are associated with isocyanates:

* higher cost,
* health and handling hazards, and
* tendency to stick to press cauls and platens.

Although it is anticipated that the price of isocyanates will drop, at present they are considerably more expensive than phenol formaldehyde resins. This puts isocyanates at a severe disadvantage, because resin costs are a very significant portion of overall OSB/waferboard manufacturing costs. On the other hand, use of isocyanates would reduce costs in other areas. More rapid curing would permit increases in plant throughput, which would lower per panel capital costs. Curing at lower temperatures would reduce fuel costs. And the use of isocyanates would give plants potential for greater flexibility in manufacturing -- more options with respect to curing temperatures and moisture content of furnish.

Isocyanate resins are potentially hazardous, owing to irritating aerosols given off during application.

Isocyanates are increasingly being used in Europe as binders for wood composites due to restrictions on formaldehyde emissions from finished boards.

3. METHODS AND MATERIALS

3.1 Materials and Panel Specifications

Seventeen (17) paanels were made from the following materials:

Furnish:		- Alberta Aspen wood
		- strands
		- Dryed unscreened face material (see Plate 1) waferized by Weldwood at Slave Lake, Alberta
		- 5.3% O.D. moisture content
Resin:	Variable:	- Polymeric diphenylmethane diisocyanate (MDI)
		- Produced by Mobay Chemical Cororation
		- Tradename: Mondur E-441 (see Appendix A for product information and material safety data sheet)
	Control:	- Powder phenol formaldehyde (PF)
		- Produced by Reichhold Company
		- Tradename: IB-947 (see Appendix B for technical bulletin)
	Wax:	- Esso 778 Slack wax

PLATE 1. Sample of Wood Furnish

The panels were made to the following specifications:

Resin Content: - Four trials were run to the resin specifications shown in Table 1.

Table 1

Panels Manufactured for Study of Isocyanates

Resin	Resin Content (to O.D. furnish weight)		
	1.5%	2.0%	2.5%
Polymeric MDI	4 panels	4 panels	4 panels
Powdered PF	---	---	5 panels

Wax Content: - 1.2% of O.D. furnish weight

Panel Construction: - homogeneous, single layer, randomly oriented strandboard

Target Thickness: - 11.1 mm (7/16 in.)

Target Density: - 650 kg/m^3 (40.5 lb/ft^3)

Panel Dimension: - 685 x 1250 mm (27 x 49.25 in.) untrimmed

- 610 x 1220 mm (24 x 48 in.) trimmed

3.2 Methods for Panel Manufacture

3.2.1 Blending

Melted wax was applied to all the furnish required for the four trials in three equal batch loads of 45 kg green weight. This was done in a 2440 mm diameter, 1220 mm deep batch drum blender (see Plate 2). The rotation of the blender was kept at approximately 20 rev/min. while the melted wax was applied through three atomizing spray nozzles at a total rate of approximately 114 g/min. A sight glass on the wax pot was used to measure the quantity applied.

The resin was applied to the furnish in a smaller 1520 mm diameter, 710 mm deep batch drum blender (see Plate 3). The rotation of the blender was kept at approximately 10 rev/min. while the resin was being applied.

The polymeric MDI was sprayed onto the furnish with an atomizing sprayer (see Plate 4) at a rate of approximately 75 g/min. The process was performed inside a well ventilated enclosure (see Plate 5) with the working personnel wearing air-supplied respirators as a precaution against inhalation of MDI vapors. The resin pot was weighed prior to and at the end of the spraying to more accurately measure the amount of resin added to the furnish. Two loads of 14.5 kg of green furnish weight were made for each resin content and then mixed together prior to forming.

For the control resin, a weighed quantity of phenolic powder was added to the furnish and was then mixed in the drum for nine (9) minutes so that the powder could distribute evenly onto the furnish. To ensure that all production variables not being measured in the production period (approximately 32 hours) did not significantly change over this time, two loads with control resin were made -- one at the beginning of the trial period (panels 1 and 2) and another at the end (panels 3, 4 and 5).

3.2.2 Forming

Each wafer mat was formed by hand in a 770 x 1320 mm retaining box (see Plate 6). The furnish was laid out in thick layers in order to reduce stacking and bridging of the strands. The mat was continually weighed during the forming process to achieve consistent densitites from panel to panel.

The mats were formed on top of a 685 x 1295 mm, 3.2 mm thick steel caul plate. An identical caul plate was placed over the formed mat prior to it being pressed (see Plate 7). A thick layer of liquid wax had to be spread over the caul plate surface facing the wafer mat to reduce the tendency of the panel bonding to the cauls.

Due to the furnish being unscreened, the fines had a tendency to settle at the bottom of the wafer mat during forming. This resulted in a noticeable difference in surface appearance and texture of the top and bottom panel surfaces.

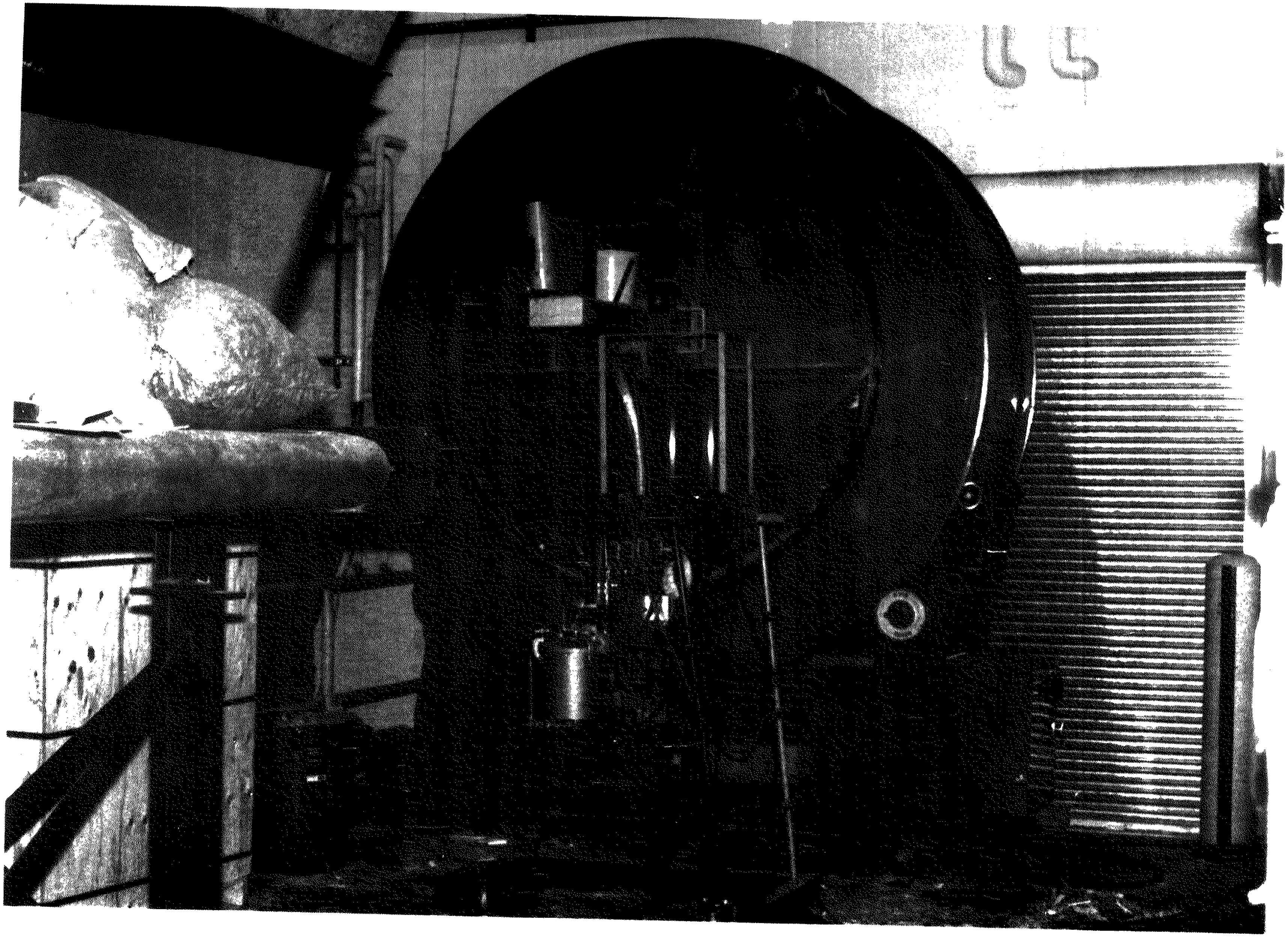


PLATE 2. 2440 mm Diameter Batch Drum Blender

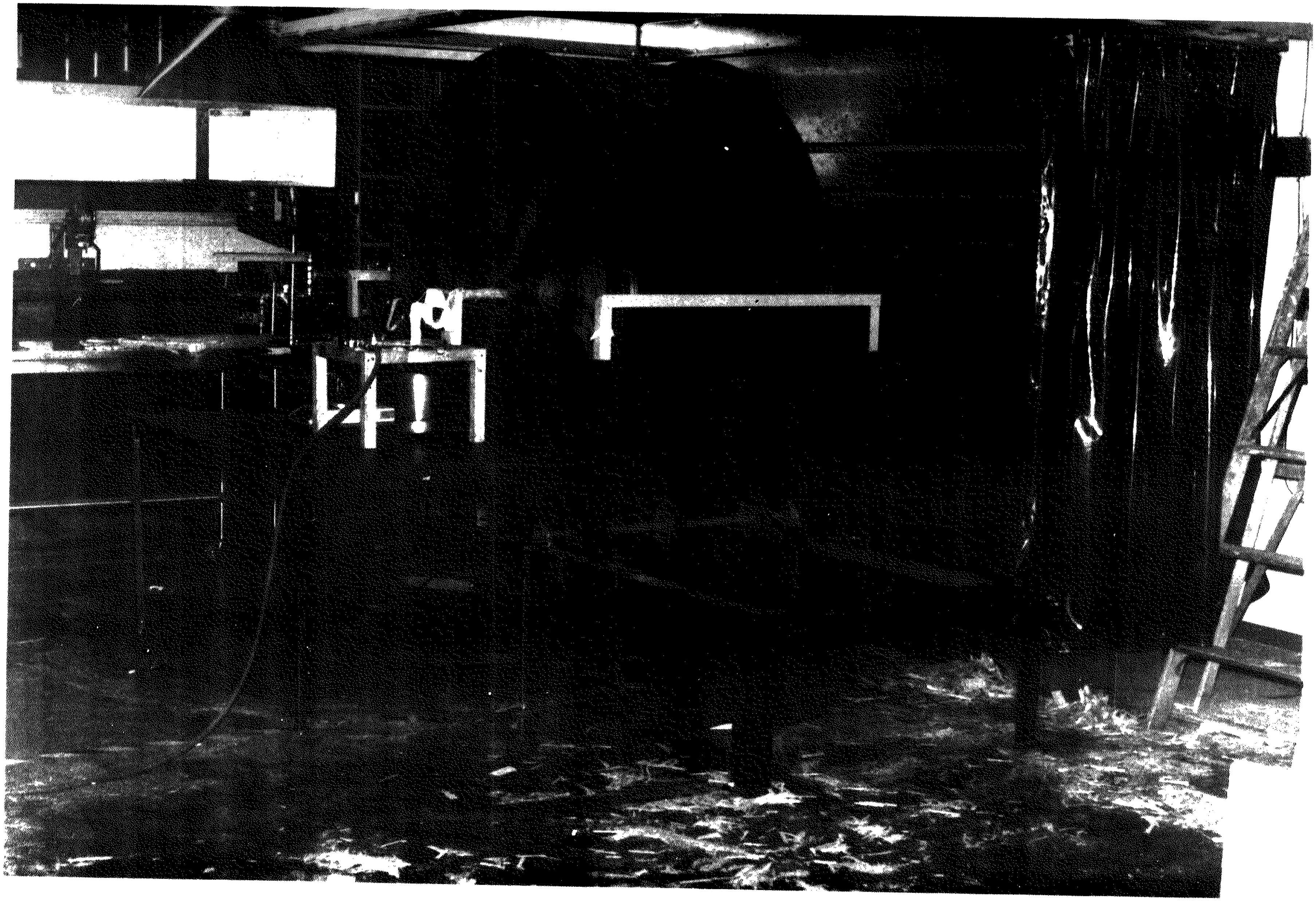


PLATE 3. 1520 mm Diameter Batch Drum Blender

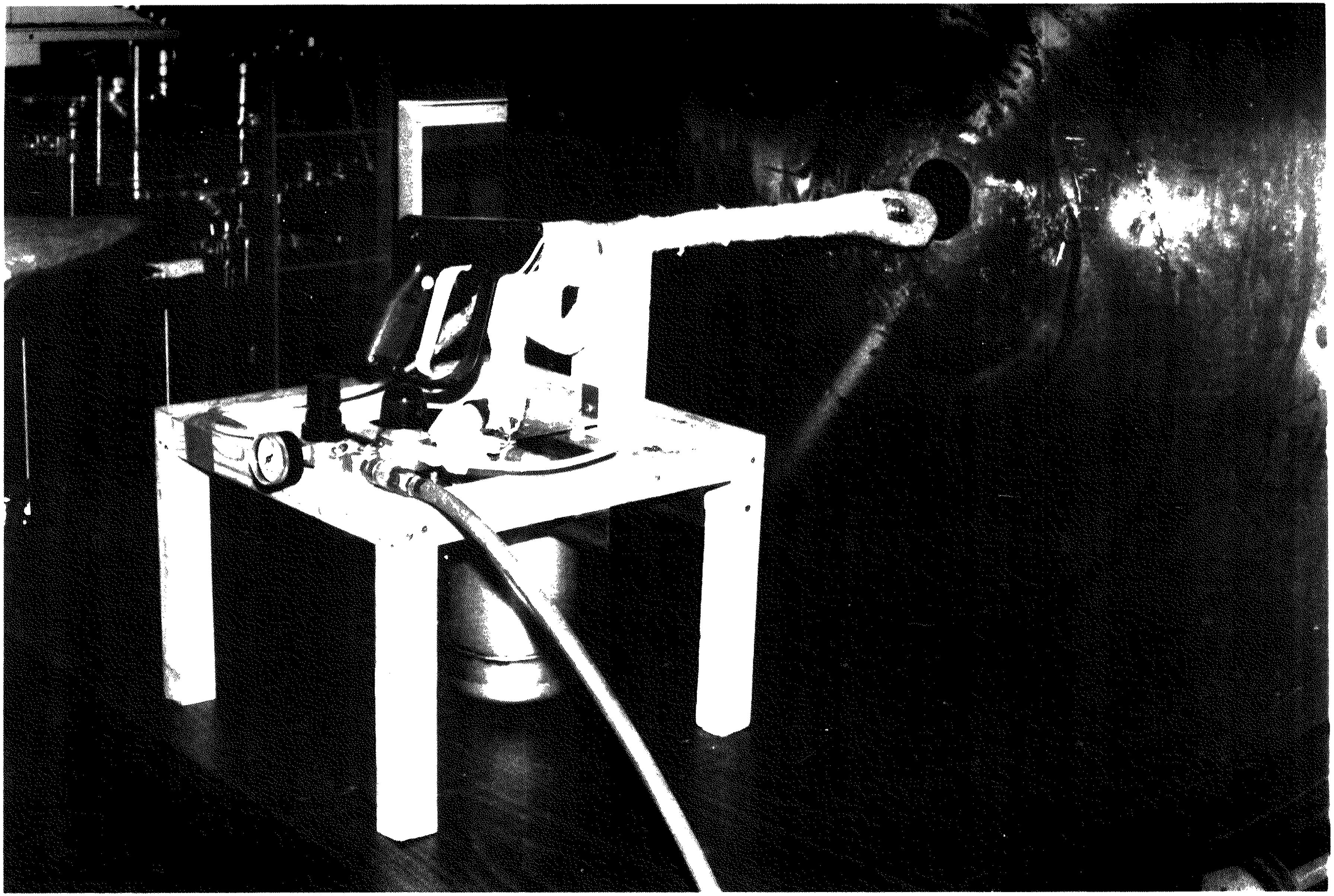


PLATE 4. Spraying Apparatus Used to Apply the Polymeric MDI to the Furnish

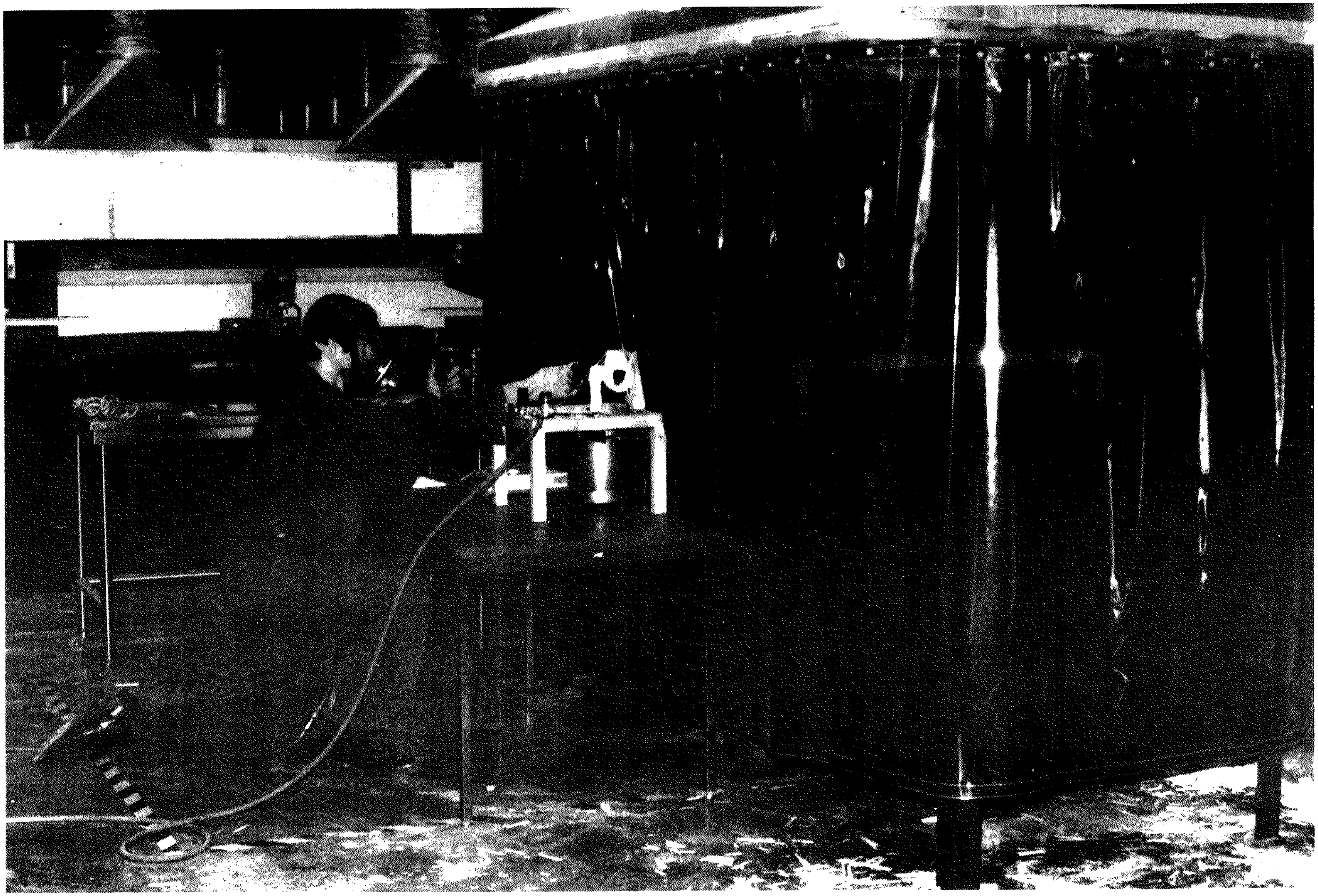


PLATE 5. Application of the Polymeric MDI to the Furnish

PLATE 6. Wafer Mat Being Hand Formed

PLATE 7. Formed Wafer Mat Ready for Pressing

3.2.3 Pressing

The panels were pressed in a 712 x 1320 mm platen area laboratory hot press (see Plate 8). The hydraulic press has a 500 ton capacity and the platens are electricallly heated with 70 kW of maximum power.

The platen temperature was set to 205 deg. C. Measurements of the coreline temperature were recorded for all panels. The temperature was consistent from panel to panel and was adequate for resin cure.

All panels were pressed to metal stops positioned at the four corners of the platens. The press closing time (PCT) or the time to stops was approximately 90 seconds. A press schedule (to pressure setopint) was run from a programmable process controller for each press cycle in order to obtain the target density and thickness. The press cycle was adjusted for each trial so that very little load was taken by the stops.

The press cycle was made up of four load stages:

a) Compression at approximately 3000 kN press load (3500 kPa panel pressure). Most of the panel compression was done in this short stage (approximately 10 seconds at maximum pressure).

b) Further compression at approximately 1600 kN press load (1900 kPa panel pressure) to attain the target thickness.

c) Decompression to approximately 600 kN press load (700 kPa panel pressure) to maintain constant thickness and to allow the resin to cure.

d) Complete decompression to nearly no press load to allow minute expansion of the panel, thus slowly releasing the hot air and steasm from the core of the panel.

To allow relatively equal cure for all the panels, the total press time not including placement and removal of the panel was kept at 4:30 minutes. In addition, the times of the four press stages were kept constant for all runs. However, due to the different amounts of resins used, the press cycle for each trial had to be modified to compensate for differences in the rate of compression and the amount of panel spring back. Plots of typical profiles of press load and panel thickness are shown in Appendix C.

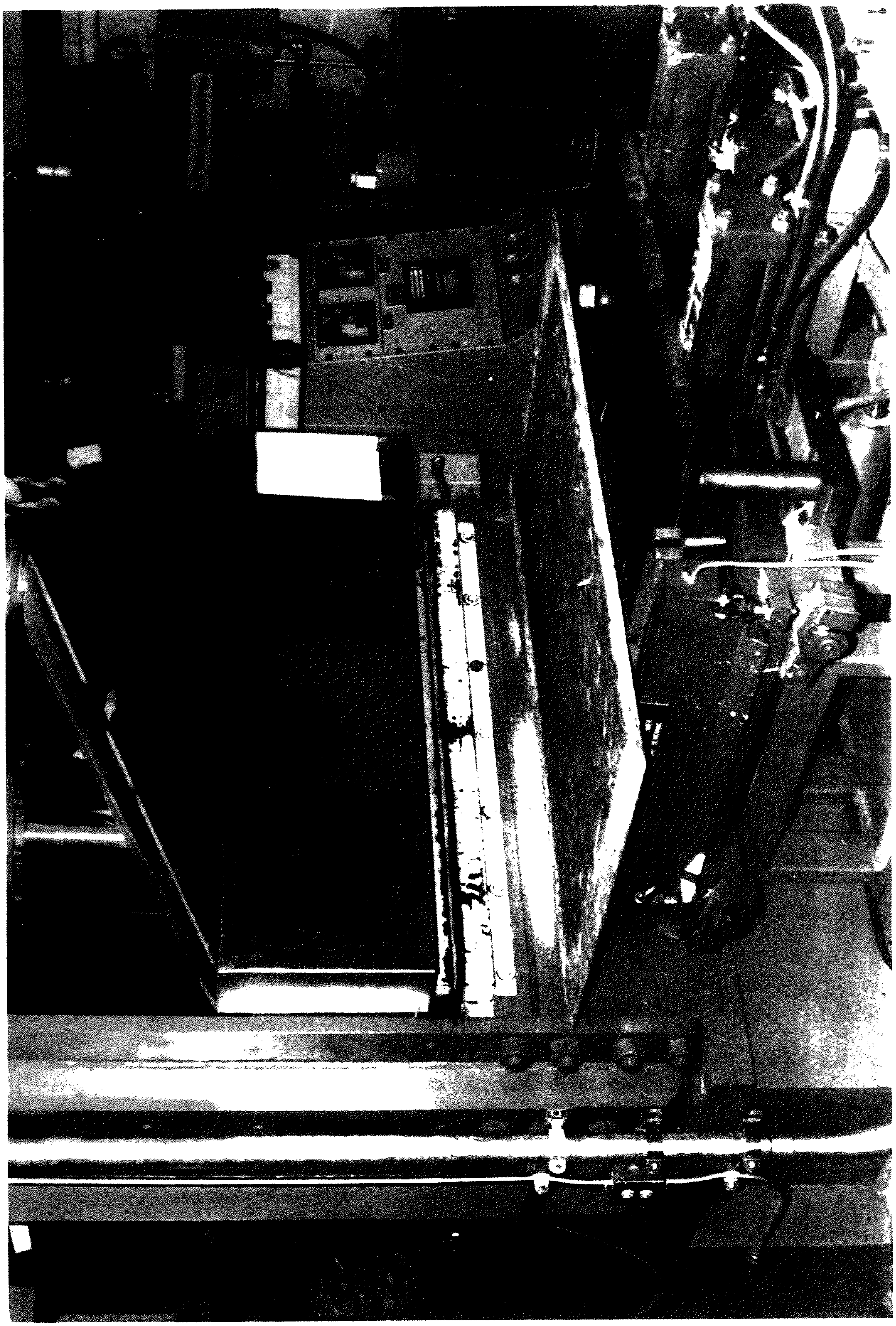


PLATE 8. 2' x 4', 500 ton Capacity, Hot Press

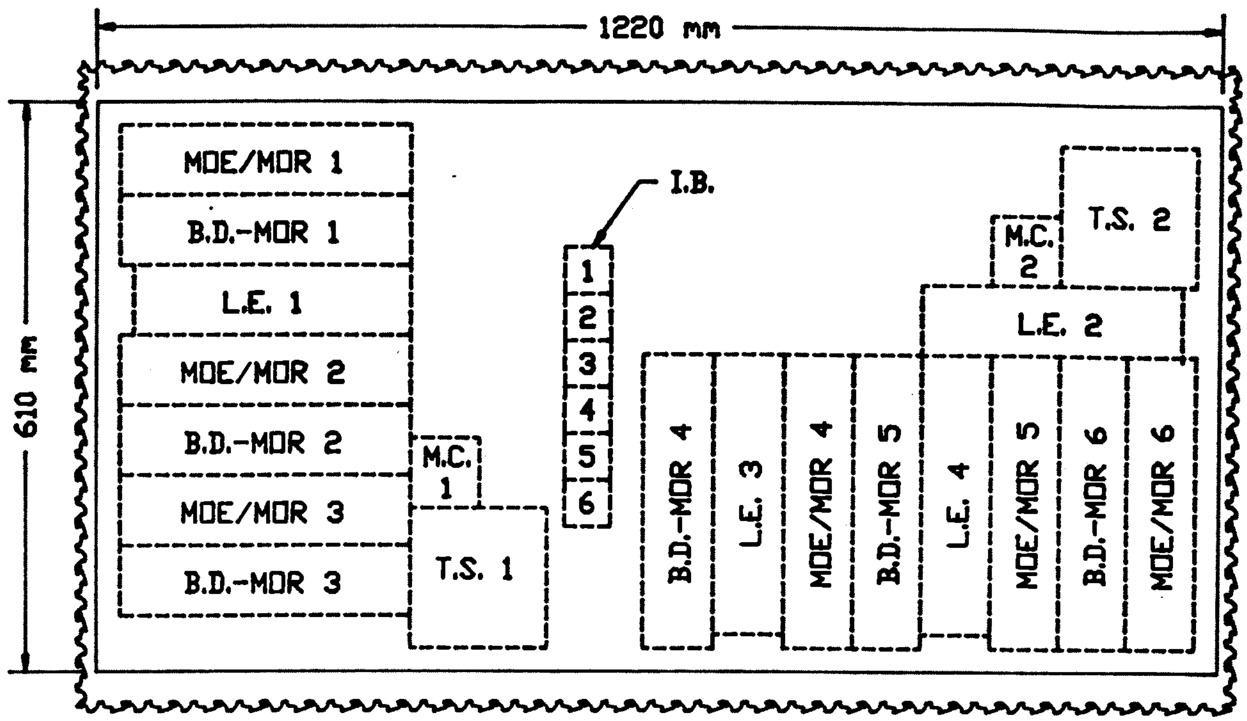
3.3 Methods for Panel Testing and Evaluation

Testing of the panels was carried out at the ARC testing laboratory.

Three panels from each isocyanate group and four PF control panels were cut into small test specimens using the cut-up pattern shown in Figure 1. These test panels were chosen for their proximity to the target density and thickness values.

Tests were conducted according to CAN3-0437.1-M, for most panel properties, and ASTM D 1037, for moisture content and density. The entire test specimen from the static bending test (for MOR and MOE) was used for the moisture and density determination. All testing not requiring special conditioning of test specimens was done in the "as received" moisture condition.

Evaluation procedures were as specified by CAN3-0437.0-M85 for Grade R-1 waferboard except as noted in Table 1. Also note that the sample size was three to four panels, and not five as specified in the CSA Standards.



Legend	Number	Size	Test
MOE/MOR	6 (1,2,3 para. 4,5,6 perp.)	75 x 315 mm	Modulus of Elasticity and Modulus of Rupture
B.D.-MOR	6 (1,2,3 para. 4,5,6 perp.)	75 x 315 mm	Bond Durability- MOR after 2 h boil
L.E.	4 (1,2 para. 3,4 perp.)	75 x 300 mm	Linear Expansion- oven dry to saturated
I.B.	6	50 x 50 mm	Internal Bond
T.S.	2	150 x 150 mm	Thickness Swell- 24 h soak
M.C.	2	75 x 75 mm	Moisture Content and Density

Figure 1: Panel Cut-up Pattern for 610 x 1220 mm Panels

TABLE 2. Test Methods for 610 x 1220 mm Panels

Test	Code	Clause	Tests/ Panel
Modulus of Rupture (MOR)	CAN3-0437.1-M	5.7	
- parallel			3
- perpendicular			3
Modulus of Elasticity (MOE)	CAN3-0437.1-M	5.7	
- parallel			3
- perpendicular			3
Internal Bond	CAN3-0437.1-M	5.8	6
Bond Durability- MOR after 2 h boil	CAN3-0437.1-M	5.9	
- parallel			3
- perpendicular			3
Thickness Swell- 24 h soak	CAN3-0437.1-M	5.11	2
Linear Expansion - oven dry to saturated	CAN3-0437.1-M	5.12	
- parallel			2
- perpendicular			2
Moisture Content	ASTM D 1037	126 & 127	2
Density	ASTM D 1037 and CAN3-0437.1-M	126 & 127; 5.2, 5.3 and 5.6	2

4. RESULTS AND DISCUSSION

4.1 Results and Discussion of Manufacture

The polymeric MDI sprayed easily onto the furnish. There was no tendency of the MDI to solidify or plug up at the tip of the spray nozzle as has been experienced with liquid PF resins (Borden Chemical's Cascophen WG-12) using this same spraying apparatus. As a result, a small size aperture could be used on the spray nozzle allowing the MDI to be sprayed in a very fine mist. Because spinning disc applicators are most widely used in industry to apply liquid resins to waferboard furnish, this apparent advantage of the MDI over liquid PF may not be as prevailing.

The MDI panels pressed similar to the PF control panels. With the exception of panels made from 1.5% MDI there was no noticeable spring-back of the panel on decompression. The panels with 1.5% resin had a small amount of spring-back and thus had to be pressed thinner in the compression stages of the cycle to allow for the increased thickness on spring-back. These panels were also pressed to thinner stops compared to the other panels.

As anticipated, the isocyanates reacted with the steel during pressing causing a few panels to stick to the cauls. The liquid wax applied over the caul surface reduced this tendency greatly. Yet, some panels still had to be forced off the cauls. Single wafers that got stuck to the cauls, usually on the untreated platen side of the caul, had to be removed with a sharp metal scraping knife.

The produced panels with MDI resin had a very light color that is desirable in terms of marketability. Furthermore, there was no visible resin concentrations or spots on the panels.

The MDI panels also appeared more stiff compared to PF panels as soon as they were removed from the press.

4.2 Test Results and Discussion of Test Results

All panels tested exceeded the CSA 0437 requirements for random panels (R-1) for the properties tested. A summary of the test results is shown in Table 3. Results for Internal Bond, Modulus of Elasticity, Modulus of Rupture, Bond Durability, Thickness Swell and Linear Expansion are shown in Tables 4 to 9 respectively. Individual test results for 1.5%, 2.0%, 2.5% MDI, and 2.5% PF panels are shown in Appendix D, E, F and G respectively.

The average of panels made from 2.0 and 2.5% MDI binder were, for all properties tested, better or equivalent to the control panels made from 2.5% powder PF.

The panels made from 1.5% MDI binder were significantly different from the control panels only in Internal Bond and Bond Durability. However, all panels with MDI binder had significantly lower thickness swell than the PF panels.

For most properties tested, there was an improvement in properties with the increase in resin content of the MDI panels. This is shown graphically for the properties tested in Figures 2 to 8. However, panels with 2.0% MDI were equivalent to panels with 2.5% MDI in most properties tested. Only thickness swell values of the 2.5% MDI panels were significanly different for 2.0% MDI panels. This would suggest that furnish sprayed with MDI binder is staurated over 2.0% resin content and increasing the resin content further may only improve the panel properties slightly.

Table 3

SUMMARY TABLE
GRADE PROPERTIES
(CAN3-0437-M85)

Client: Alberta Research Council
Test Date: March 30, 1987
Proj.Ref.: 303221

Test Material: All Types of Waferboard
Nom. Thickness: 11.1 mm
Conditioning: As per test requirements

	Units	CAN3-0437 R-1 Req.	Dir'n	MDI Panels (3 Panel Avg.) 1.5%	MDI Panels (3 Panel Avg.) 2.0%	MDI Panels (3 Panel Avg.) 2.5%	PF Resin Panel (4 Panel Avg.) 2.5%
Modulus of rupture	MPa	17.2	Para	29.2	35.9	37.4	32.8
		17.2	Perp	30.2	32.2	32.6	30.9
Modulus of elasticity	MPa	3100	Para	5170	5530	6200	5050
		3100	Perp	4900	5330	4970	4930
Internal bond	MPa	0.345		0.499	0.646	0.637	0.608
Bond durability - MOR after 2 h boil	MPa	8.6	Para	14.5	17.1	17.0	17.4
		8.6	Perp	12.3	17.3	16.7	18.3
Thickness swell - 24 h soak - 12.7 mm or thinner	%	25		13	13	10	16
Linear expansion - oven dry to saturated	%	0.40	Para	0.28	0.24	0.28	0.26
		0.40	Perp	0.25	0.27	0.24	0.24
General							
Moisture Content	%	8 max.		3	3	3	4
Density	kg/cu.m	None		651	678	673	659

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FOREST PRODUCTS LABORATORY

TABLE 4. Ranking for Internal Bond Strength

Resin	Resin Content (%)	Panel No.	Bond Strength (MPa)	Combined Average[1] Bond Strength (MPa)	Combined Average[1] Rank[2]	Combined Average[1] Std. Dev. (MPa)
MDI	2.0	2.0-1	0.622	0.646	A	0.085
		2.0-2	0.699			
		2.0-4	0.616			
MDI	2.5	2.5-1	0.593	0.637	A	0.140
		2.5-2	0.613			
		2.5-4	0.707			
PF	2.5	PF-2	0.630	0.608	A	0.066
		PF-3	0.593			
		PF-4	0.631			
		PF-5	0.580			
MDI	1.5	1.5-1	0.438	0.499	B	0.111
		1.5-3	0.569			
		1.5-4	0.489			

[1] Combined average values based on six samples per panel (N = 6 * No. of Panels)

[2] Values of Bond Strength having the same capital letter are not significantly different (two sample T-test, $\alpha = 0.05$, pooled variance used where variance of both samples was found not significantly different using F-test for variance ratio with $\alpha = 0.05$)

TABLE 5. Ranking for Modulus of Elasticity (MOE)

Resin	Resin Content (%)	Panel No.	MOE Para. (MPa)	MOE Perp. (MPa)	Combined Average[1] MOE (MPa)	Rank[2]	Std. Dev. (MPa)
MDI	2.5	2.5-1 2.5-2 2.5-4	6600 5500 6500	4800 5100 5000	5570	A	1030
MDI	2.0	2.0-1 2.0-2 2.0-4	5400 5900 5300	5200 5700 5100	5470	A	760
MDI	1.5	1.5-1 1.5-3 1.5-4	5200 5100 5200	5000 4900 4800	5040	AB	650
PF	2.5	PF-2 PF-3 PF-4 PF-5	4800 5000 5300 5100	4200 5400 5200 4900	4990	B	630

[1] Combined average values based on six samples (3 parallel, 3 perpendicular) per panel (N = 6 * No. of Panels)

[2] Values of MOE having the same capital letter are not significantly different (two sample T-test, $\alpha = 0.05$, pooled variance used where variance of both samples was found not significantly different using F-test for variance ratio with $\alpha = 0.05$)

TABLE 6. Ranking for Modulus of Rupture (MOR)

Resin	Resin Content (%)	Panel No.	MOR Para. (MPa)	MOR Perp. (MPa)	Combined Average[1] MOR (MPa)	Combined Average[1] Rank[2]	Combined Average[1] Std. Dev. (MPa)
MDI	2.5	2.5-1	38.2	33.2	35.2	A	5.0
		2.5-2	35.7	35.3			
		2.5-4	38.2	30.4			
MDI	2.0	2.0-1	35.6	31.6	33.5	AB	6.1
		2.0-2	39.4	33.5			
		2.0-4	32.6	31.6			
PF	2.5	PF-2	29.6	27.1	31.8	B	5.3
		PF-3	32.7	33.0			
		PF-4	32.9	35.2			
		PF-5	35.8	28.3			
MDI	1.5	1.5-1	30.9	29.3	29.7	B	5.2
		1.5-3	27.3	30.8			
		1.5-4	29.4	30.5			

[1] Combined average based on six samples (3 parallel, 3 perpendicular) per panel (N = 6 * No. of Panels)

[2] Values of MOR having the same capital letter are not significantly different (two sample T-test, $\alpha = 0.05$, pooled variance used where variance of both samples was found not significantly different using F-test for variance ratio with $\alpha = 0.05$)

TABLE 7. Ranking for Bond Durability-MOR after 2 h Boil

Resin	Resin Content (%)	Panel No.	MOR Para. (MPa)	MOR Perp. (MPa)	Combined Average[1] MOR (MPa)	Combined Average[1] Rank[2]	Combined Average[1] Std. Dev. (MPa)
		PF-2	17.0	17.7			
PF	2.5	PF-3	17.4	19.3	17.8	A	2.4
		PF-4	19.0	15.9			
		PF-5	16.3	20.1			
		2.0-1	19.7	18.3			
MDI	2.0	2.0-2	15.7	16.8	17.2	A	2.1
		2.0-4	15.9	16.9			
		2.5-1	16.5	18.0			
MDI	2.5	2.5-2	18.8	16.9	16.9	A	3.1
		2.5-4	15.7	15.3			
		1.5-1	14.0	11.8			
MDI	1.5	1.5-3	15.0	13.1	13.4	B	2.6
		1.5-4	14.4	12.1			

[1] Combined average based on six samples (3 parallel, 3 perpendicular) per panel (N = 6 * No. of Panels)

[2] Values of MOR having the same capital letter are not significantly different (two sample T-test, $\alpha = 0.05$, pooled variance used where variance of both samples was found not significantly different using F-test for variance ratio with $\alpha = 0.05$)

TABLE 8. Ranking for Thickness Swell-24 h Soak

Resin	Resin Content (%)	Panel No.	Thickness Swell (%)	Combined Average[1] Thickness Swell (%)	Rank[2]	Std. Dev. (%)
		2.5-1	9			
MDI	2.5	2.5-2	10	9.9	A	1.9
		2.5-4	11			
		2.0-1	13			
MDI	2.0	2.0-2	13	12.9	B	2.5
		2.0-4	13			
		1.5-1	14			
MDI	1.5	1.5-3	14	13.3	B	2.4
		1.5-4	11			
		PF-2	17			
PF	2.5	PF-3	15	15.9	C	2.4
		PF-4	16			
		PF-5	17			

[1] Combined average based two samples (four measurements at four positions) per panel (N = 8 * No. of Panels)

[2] Values of Thickness Swell having the same capital letter are not significantly different (two sample T-test, $\alpha = 0.05$, pooled variance used where variance of both samples was found not significantly different using F-test for variance ratio with $\alpha = 0.05$)

TABLE 9. Ranking for Linear Expansion-Oven Dry to Saturated

Resin	Resin Content (%)	Panel No.	L.E. Para. (%)	L.E. Perp. (%)	Combined Average[1] Linear Expansion (%)	Rank[2]	Std. Dev. (%)
		PF-2	0.19	0.26			
PF	2.5	PF-3	0.23	0.25	0.25	A	0.07
		PF-4	0.28	0.19			
		PF-5	0.35	0.25			
		2.0-1	0.24	0.27			
MDI	2.0	2.0-2	0.25	0.22	0.25	A	0.08
		2.0-4	0.21	0.32			
		2.5-1	0.22	0.25			
MDI	2.5	2.5-2	0.30	0.14	0.26	A	0.08
		2.5-4	0.31	0.33			
		1.5-1	0.25	0.22			
MDI	1.5	1.5-3	0.33	0.34	0.26	A	0.07
		1.5-4	0.24	0.19			

1 Combined average based on four samples (2 parallel, 2 perpendicular) per panel (N = 4 * No. of Panels)

2 Values of Linear Expansion having the same capital letter are not significantly different (two sample T-test, $\alpha = 0.05$, pooled variance used where variance of both samples was found not significantly different using F-test for variance ratio with $\alpha = 0.05$)

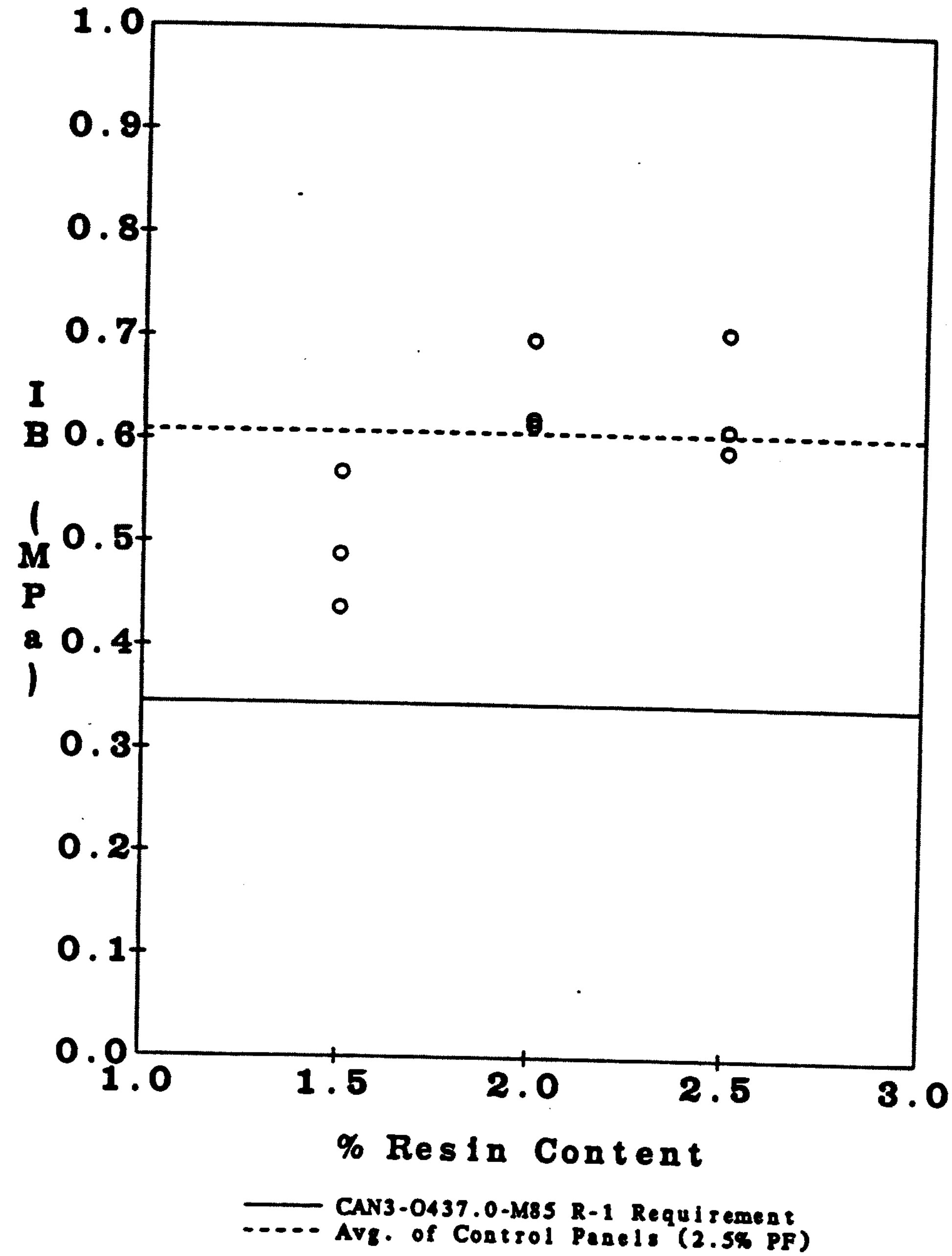

Figure 2: Internal Bond Strength vs. MDI Binder Content

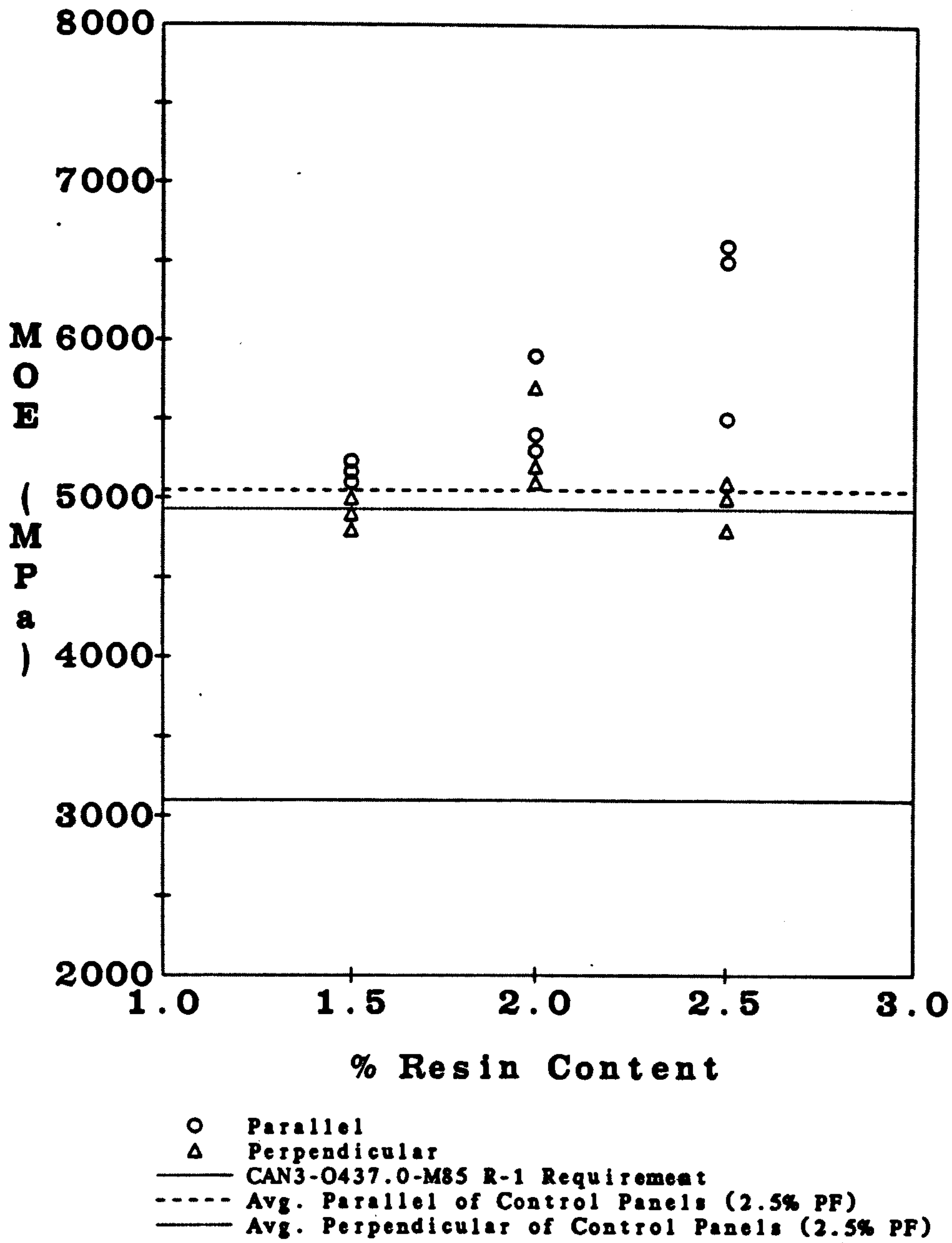

Figure 3: Modulus of Elasticity (MOE) vs. MDI Binder Content

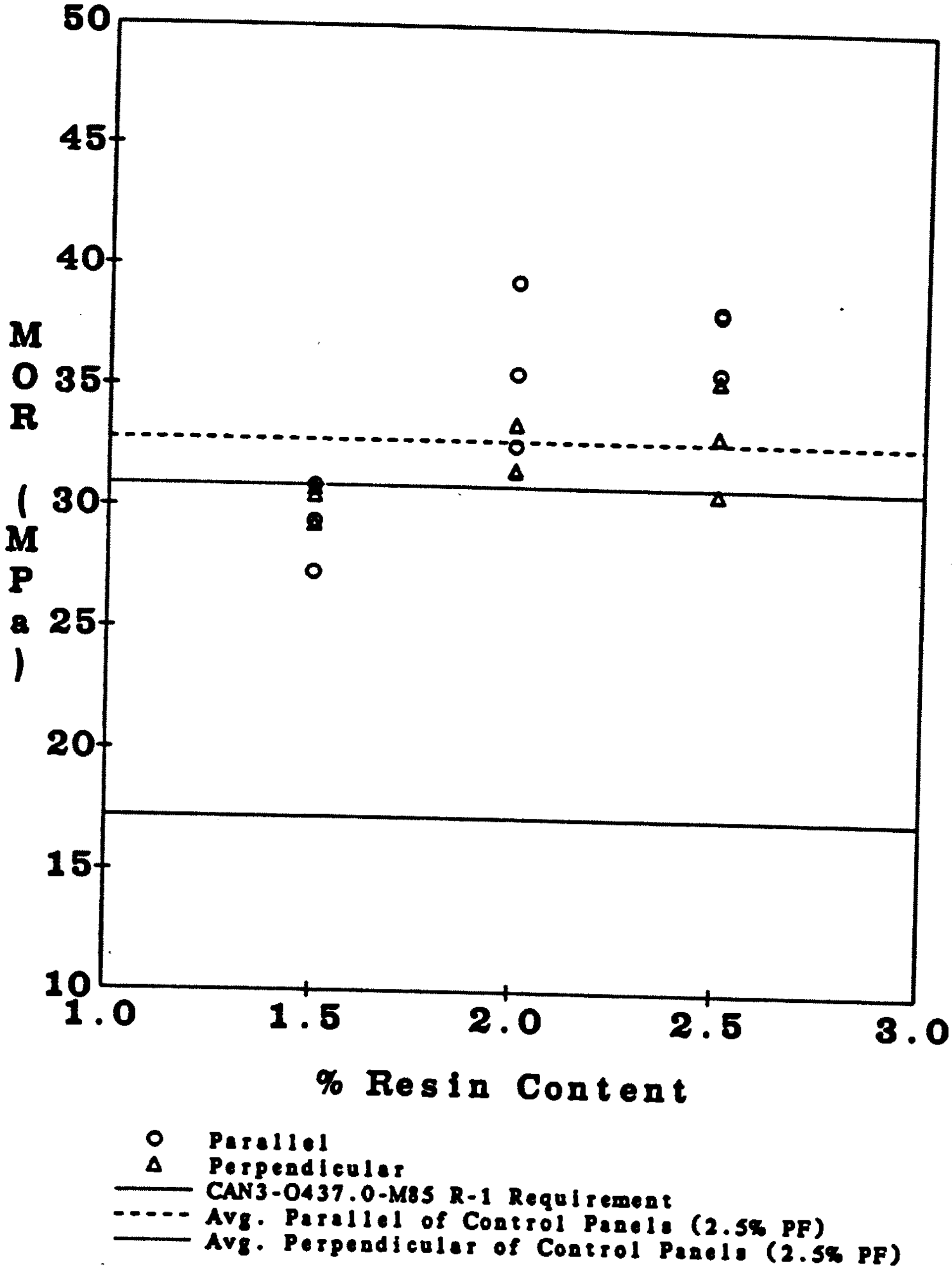

Figure 4: Modulus of Rupture (MOR) vs. MDI Binder Content

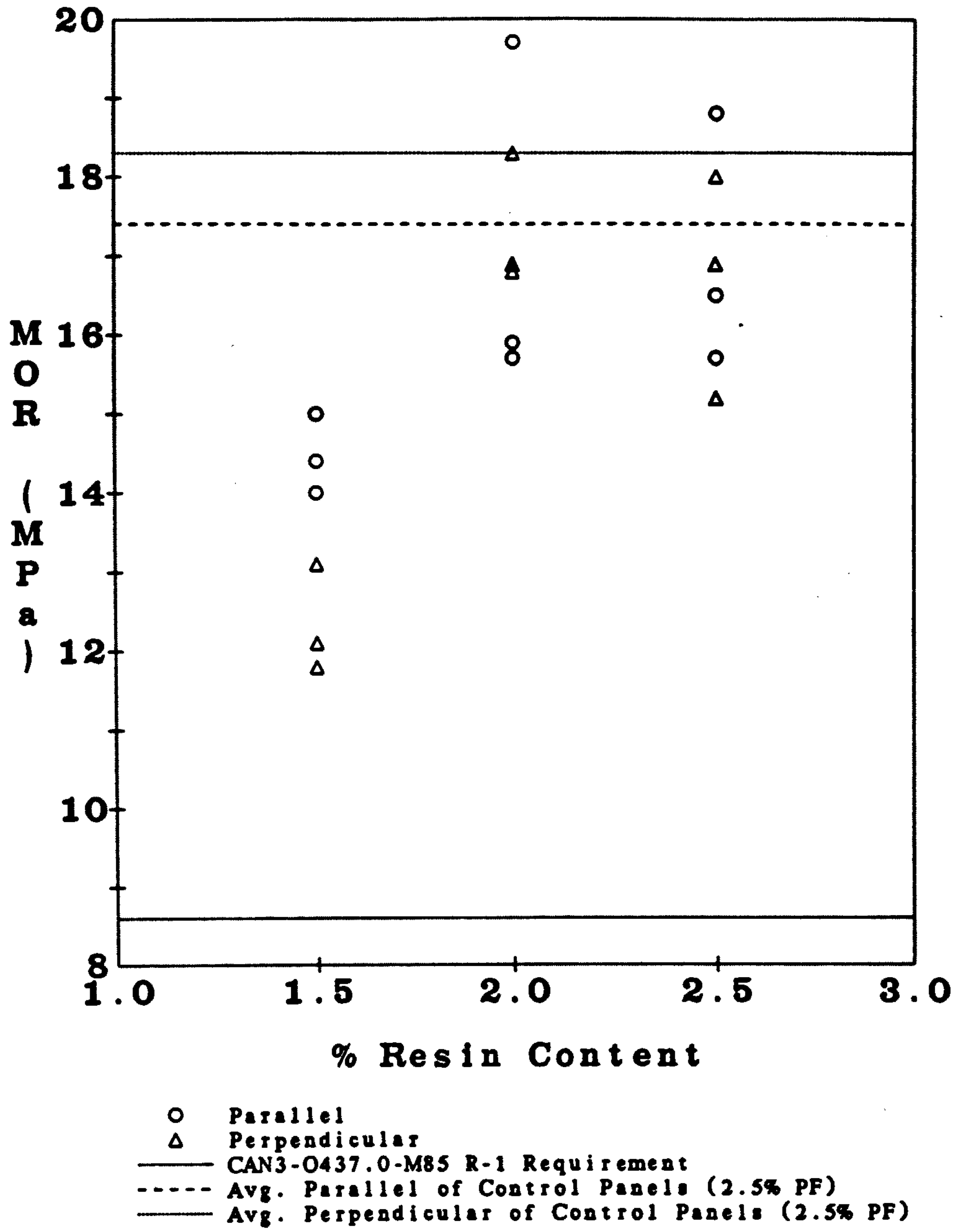

Figure 5: Bond Durability -- MOR after 2 Hr. Boil
vs. MDI Binder Content

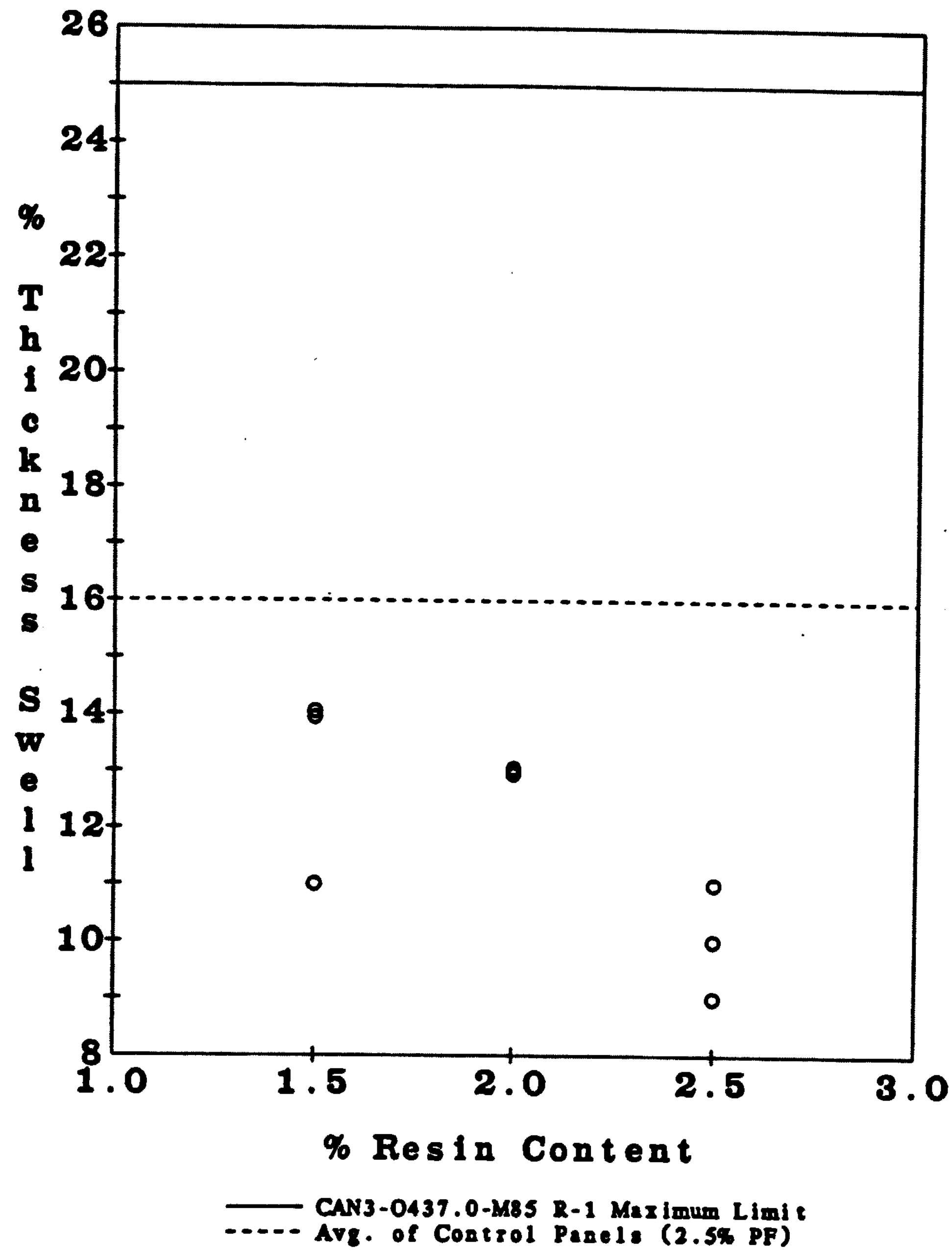

Figure 6: Thickness Swell -- 24 Hr. Soak vs. MDI Binder Content

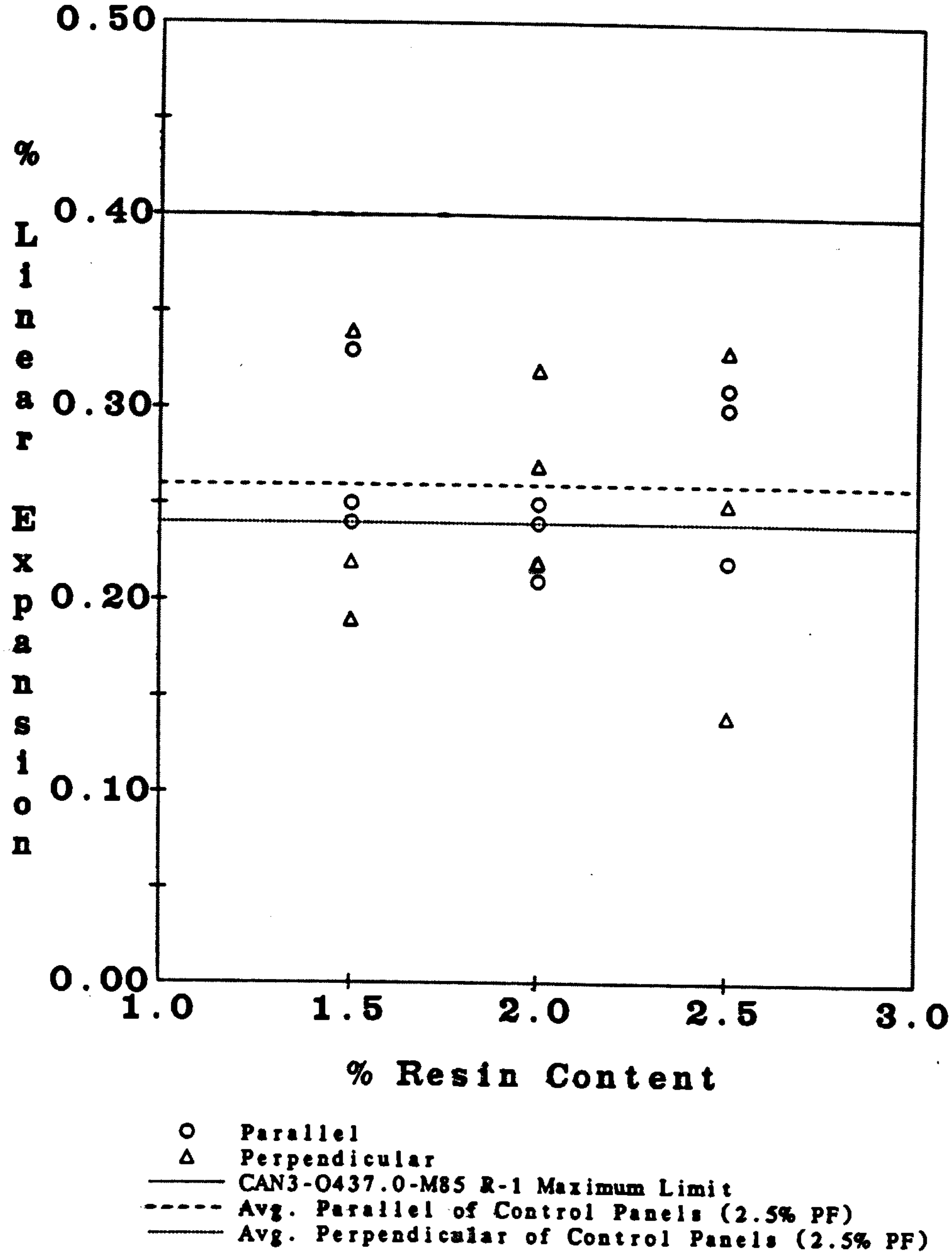

Figure 7: Linear Expansion -- Oven Dry to Saturated vs. MDI Binder Content

5. CONCLUSION

A contract was awarded to Forintek Canada Corp., who conducted a state-of-the-art review on the use of isocyanates in bonding wood composites. The finding in the state-of-the-art review was supported by the work done in the ARC laboratory.

Seventeen panels were produced, using isocyanate resins at three different levels, with powdered phenol formaldehyde resin as a control. The results show that manufacture of panels using isocyanate resin is technically feasible. During production it was observed that MDI panels had:

- good application properties as compared to liquid PF resins
- desirable (non brown) surface color of finished panels
- tendency to stick to cauls

The panels made with isocyanate binder demonstrated equivalent or improved properties over those made with phenol formaldehyde, for similar and, in some cases, for lower resin levels:

* thickness swell: isocyanates much better,
* modulus of elasticity: isocyanates better,
* modulus of rupture: isocyanates better,
* bond durability after two hour boil: no difference,
* linear expansion: no difference, and
* internal bond: no difference.

As isocyanates pose potential health and handling hazards, special precautions were taken, resulting in useful experience for future manufacturing.

6. COMMERCIAL SIGNIFICANCE

As engineered wood composites offer the most potential for utilization of Alberta's low diameter resources, an improvement in marketability or a reduction in production cost of wood composites, such as OSB, will benefit the growing Alberta forest products industry and thus improve the economic base of Alberta.

It appears from this study that the use of isocyanate binders in OSB production could significantly increase the marketability of OSB due to:

- an increase in panel strength
- a decrease in panel thickness swell
- no formaldehyde emissions, and
- an improvement in panel appearance.

In addition, production costs could be reduced because of:

- faster cure time
- lower cure temperatures, and
- higher moisture content of furnish.

Admittedly, the price of isocyanates still remains high and there are still a few problems in production, but it is anticipated that these disadvantages will be overcome. The province of Alberta will gain if this is so.

7. RECOMMENDATIONS

It is recommended that further work be done with isocyanate binders in the ARC laboratory because of the potential benefits to Alberta OSB producers. The use of isocyanate binders may reduce production costs and increase the marketability of OSB.

Potential areas of study include:

* optimization of resin levels,
* optimization of press schedules (shorter press times, lower temperatures),
* steam injection pressing,
* catylyst incorporation,
* higher furnish moisture content,
* development of new/evaluation of existing liquid resin applicators (such as spinning disc applicators), and
* evaluation of different isocyanate types.

8. REFERENCES

Steiner, P. R. 1986. Bonding Wood Composites with Isocyanates. ARC Forest Products file FPLC-2. Edmonton, Alberta.

Canadian Standards Association. 1985. CAN3-0437.0-M85 Waferboard and Strandboard. Toronto, Ontario.

Canadian Standards Association. 1985. CAN3-0437.1-M85 Test Methods for Waferboard and Strandboard. Toronto, Ontario.

American Society for Testing and Materials. 1985. Standard Methods of Evaluating Properties of Wood-base Fibre and Particle Panel Materials. ASTM D 1037-78. Philadelphia, Pa.

ARC, Internal Report. FPLI-40: Isocyanates (MDI).

ARC, Quarterly Report, FPQR-86/87-1: Covering period April 1 - June 30, 1986

ARC, Quarterly Report, FPQR-86/87-2: Covering period July 1 - September 30, 1986.

ARC, Quarterly Report, FPQR-87/87-3: Covering period October 1 - December 31, 1986.

APPENDIX A

Product Information for

Mobay Mondur E-441 Binder

Mobay

**Mobay
Chemical Corporation**

Polyurethane Division

Product Information

Mondur E-441

**Polymethylene Polyphenyl Isocyanate
Product Code: G-441**

1. Description

A dark brown liquid polyisocyanate having a slight aromatic odor.

2. Typical Properties

Viscosity, at 25°C, mPa·s	200
Vapor Pressure, mm Hg at 25°C	<1 x 10⁻⁴
Weight Per Gallon, lbs.	10.3
Specific Gravity at 25°C	1.24
Flash Point, (PMCC) °C	199
Pour Point, °C	−18

3. Storage

Mondur E-441 must be stored in tightly closed containers and protected from moisture and foreign materials. Storage should be maintained at room temperature (18-24°C).

4. Application

Mondur E-441 is used as an adhesive in the manufacture of structural wood products. It is also used with suitable polyols in applications requiring urethane adhesive systems.

For information on Physiological Considerations and Handling, contact the Industrial Hygiene Department of Mobay's Polyurethane Division (412-777-2000).

Mobay Chemical Corporation • Polyurethane Division, Mobay Road, Pittsburgh, PA 15205-9741 • 412 777-2000

Sales Offices:

Raritan Plaza III, Edison, NJ 08837
3200 Gilchrist Rd., Box 6252, Akron, OH 44312
3221 W. Big Beaver Rd., Troy, MI 48084
9801 W. Higgins Rd., Rosemont, IL 60018
8455 Dunwoody Place, Atlanta, GA 30338
4101 Westerly Place, Newport Beach, CA 92660

MATERIAL SAFETY DATA SHEET

DIVISION ADDRESS

Mobay Chemical Corporation
Polyurethane Division
Penn Lincoln Parkway West
Pittsburgh, Pennsylvania 15205

ISSUE DATE 3-5-84
SUPERSEDES 1-31-84

TRANSPORTATION EMERGENCY: CALL CHEMTREC TELEPHONE NO: 800-424-9300; DISTRICT OF COLUMBIA: 202-483-7616	MOBAY NON-TRANSPORTATION EMERGENCY NO.: 412-923-1800

I. PRODUCT IDENTIFICATION

PRODUCT NAME.............: Mondur E-441
PRODUCT CODE NUMBER......: G-441
CHEMICAL FAMILY..........: Aromatic Isocyanate
CHEMICAL NAME............: Isocyanic acid, polymethylenepolyphenylene ester
SYNONYMS.................: Polymeric diphenylmethane diisocyanate (MDI)
CAS NUMBER...............: 9016-87-9
T.S.C.A. STATUS..........: On Inventory

II. HAZARDOUS INGREDIENTS

COMPONENTS:	%:	CURRENT TLV:
Diphenylmethane Diisocyanate (MDI) CAS #26447-40-5	About 50	0.02 ppm (0.2 mg/m^3) ceiling value
Phenyl Isocyanate CAS #103-71-9	Trace (ppm)	Use 0.02 ppm as guide
Higher Oligomers of MDI CAS #9016-87-9	About 50	Use 0.02 ppm as guide

III. PHYSICAL DATA

APPEARANCE...............: Liquid
COLOR....................: Dark brown
ODOR.....................: Slightly musty odor
MOLECULAR WEIGHT.........: About 350
MELT POINT/FREEZE POINT..: Below 32°F (0°C)
BOILING POINT............: 406°F(208°C) at 5 mmHg
VAPOR PRESSURE...........: Less than 10^{-5} mmHg at 77°F (25°C)
VAPOR DENSITY (AIR=1)....: 8.5 (MDI)
SPECIFIC GRAVITY.........: 1.24 at 77°F (25°C)
BULK DENSITY.............: 10.3 lbs/gal(U.S.)
SOLUBILITY IN WATER......: Reacts slowly with water to liberate CO_2 gas
% VOLATILE BY VOLUME.....: Negligible

IV. FIRE & EXPLOSION DATA

FLASH POINT °F(°C).......: 410°F (210°C) Pensky-Martin Closed Cup
EXTINGUISHING MEDIA......: Dry chemical (e.g. monoammonium phosphate, potassium sulfate, and potassium chloride), carbon dioxide, high expansion (proteinic) chemical foam, water spray for large fires.
SPECIAL FIRE FIGHTING PROCEDURES/UNUSUAL FIRE OR EXPLOSION HAZARDS:
Full emergency equipment with self-contained breathing apparatus should be worn by fire fighters. During a fire, MDI vapors and other irritating, highly toxic gases may be generated by thermal decomposition or combustion. (See Section VIII.) At temperatures greater than 400°F (204°C), polymeric MDI can polymerize and decompose which can cause pressure build-up in closed containers. Explosive rupture is possible. Therefore, use cold water to cool fire-exposed containers.

MB 321 REV 1/83

V. HEALTH EFFECTS DATA

ANIMAL TOXICITY -
ORAL, LD50
(INGESTION)..........: Greater than 20 g/kg (Rat)
DERMAL, LD50
(SKIN CONTACT).......: Greater than 15.8 g/kg (Rabbits)
INHALATION, LC50.(4 hr): Approximately 370 mg/m^3 (Rat)
AQUATIC LC50.(24 hr)...: Greater than 500 mg/l (Daphnea, Limnea Invertebrates and Zebra Fish).
EYE EFFECTS............: Not irritating (Rabbits) OECD Guidelines.
SKIN EFFECTS...........: Slight irritation (Rabbits) OECD Guidelines.
Skin sensitizer in guinea pigs.

OTHER..................: No conclusive evidence has been developed to indicate that polymeric MDI is carcinogenic, teratogenic or that it causes reproductive effects in animals or humans. However, MDI has been reported by NIOSH to be mutagenic to Salmonella typhimurium bacteria in the presence of a mammalian liver activating system (commonly called the Ames test). There is not full agreement in the scientific community on the significance of these Ames test results and their relationship to human safety in assessing the risk of cancer in man. Preliminary steps for an animal lifetime inhalation study on polymeric MDI have been performed.

HUMAN EFFECTS
OF OVEREXPOSURE........: Inhalation. Inhalation of MDI vapors or aerosols in concentrations above 0.02 ppm can produce irritation of the mucous membranes in the respiratory tract, running nose, sore throat, productiva cough and a reduction in lung function. Extensive exposures to concentrations well above the TLV could lead to bronchitis, bronchial spasm and pulmonary edema. These effects are usually reversible. However, due to low volatility, high exposures are not anticipated except if the material is overheated or sprayed as an aerosol into the air. Hypersensitivity pneumonitis has also been reported. Another type of response is hyperreactivity or hypersensitization. Persons with a preexisting unspecific bronchial hyperreactivity or persons with a specific isocyanate hypersensitivity (as a result of previous repeated overexposure or a single large dosage) will respond to small isocyanate concentrations at levels well below the TLV of 0.02 ppm. Symptoms could be immediate or delayed and include chest tightness, respiratory distress or asthmatic attack. Skin. Polymeric MDI reacts with skin protein and tissue moisture and can cause localized irritation as well as discoloration. Prolonged contact could produce reddening, swelling, or blistering and, in some individuals, skin sensitization resulting in dermatitis. Eyes. Liquid , vapors, or aerosols are irritating to the eyes and can cause lachrymation (tearing effect). Corneal damage can occur; however, indications are that the damage is reversible and does not result in permanent injury. Ingestion. Ingestion could result in - irritation and some corrosive action in the mouth, stomach tissue and digestive tract. However, it is not considered a common occupational route of exposure.

THRESHOLD LIMIT VALUE (ACGIH): 0.02 ppm (0.2 mg/m^3) ceiling for MDI.
PERMISSIBLE EXPOSURE
LIMIT (OSHA)..........: Same as TLV

VI. EMERGENCY & FIRST AID PROCEDURES

EYE CONTACT..............: Flush with clean, luke warm water (low pressure) for at least 15 minutes, occasionally lifting eyelids, and obtain medical attention.

SKIN CONTACT.............: Remove contaminated clothing. Wash affected areas thoroughly with soap and water. Wash contaminated clothing thoroughly before reuse.

INHALATION...............: Move to an area free from risk of further exposure. Administer oxygen or artificial respiration as needed. Obtain medical attention. Asthmatic-type symptoms may develop and may be immediate or delayed up to several hours. Treatment is essentially symptomatic.

INGESTION................: Do not induce vomiting. Give 250 ml of milk or water to drink. DO NOT GIVE ANYTHING BY MOUTH TO AN UNCONSCIOUS PERSON. Consult physician.

NOTE TO PHYSICIAN.......... Medical supervision of all employees who handle or come in contact with polymeric MDI is recommended. These should include preemployment and periodic medical examinations with respiratory function tests (FEV,FVC as a minimum). Persons with asthmatic-type conditions, chronic bronchitis, other chronic respiratory diseases or recurrent skin eczema or sensitization should be excluded from working with MDI. Once a person is diagnosed as sensitized to MDI, no further exposure can be permitted.

VII. EMPLOYEE PROTECTION RECOMMENDATIONS

EYE PROTECTION...........: Liquid chemical goggles or full-face shield. Contact lenses should not be worn.

SKIN PROTECTION..........: Chemical resistant gloves (natural rubber, polyvinyl alcohol). Cover as much of the exposed skin area as possible with appropriate clothing. If skin creams are used, keep the area covered by the cream to a minimum.

RESPIRATORY PROTECTION...: An air-supplied respirator must be worn during long-term (over 1 hour) exposures in environments of concentrations above the TLV of 0.02 ppm. For short-term (less than 1 hour) situations at concentrations near the TLV, an air-purifying respirator equipped with organic cartridges or cannisters and dust filters can be used. However, due to the poor warning properties of MDI, proper fit and timely replacement of filter elements must be ensured. Observe OSHA regulations for respirator use (29 CFR 1910.134).

VENTILATION..............: Local exhaust should be used to maintain levels below the TLV whenever MDI is processed or heated.

OTHER....................: Safety showers and eyewash stations should be available. Educate and train employees in safe use of product. Follow all label instructions. For additional information, See Mobay's "Health and Safety Information for Diphenylmethane Diisocyanate (MDI) - Monomeric, Polymeric, and Modified" MDI 83N.

VIII. REACTIVITY DATA

STABILITY................: Stable under normal conditions
POLYMERIZATION...........: May occur if in contact with moisture or other materials which react with isocyanates. May occur at temperatures over 400°F(204°C). See Section IV.
INCOMPATIBILITY
(MATERIALS TO AVOID)...: Water, amines, strong bases, alcohols. Will cause some corrosion to copper alloys and aluminum.
HAZARDOUS DECOMPOSITION
PRODUCTS...............: By high heat and fire: carbon monoxide, oxides of nitrogen, traces of HCN, MDI.

IX. SPILL OR LEAK PROCEDURES

STEPS TO BE TAKEN IN CASE MATERIAL IS RELEASED OR SPILLED:
Cover the spill with sawdust, vermiculite, Fuller's earth or other absorbent material. Pour decontamination solution over spill area and allow to react for at least 10 minutes. Collect material in open containers and add further amounts of decontamination solution. Remove containers to a safe place, cover loosely, and allow to stand for 24 to 48 hours. Wash down spill area with decontamination solutions. Decontamination solutions: non-ionic surfactant Union Carbide's Tergitol TMN-10 (20%) and water (80%); concentrated ammonia (3-8%), detergent (2%) and water (90-95%). Respiratory protection is recommended during spill clean-up. (See Respiratory Protection, Section VII.)
WASTE DISPOSAL METHOD: Waste must be disposed of in accordance with federal, state, and local environmental control regulations. Incineration is the preferred method. Empty containers must be handled with care due to product residue. Decontaminate containers prior to disposal. DO NOT HEAT OR CUT EMPTY CONTAINER WITH ELECTRIC OR GAS TORCH. (See Sections IV. and VIII.)

X. SPECIAL PRECAUTIONS & STORAGE DATA

STORAGE TEMPERATURE
(MIN./MAX.)............: 64°F (18°C)/86°F (30°C)
AVERAGE SHELF LIFE.......: 6 months
SPECIAL SENSITIVITY
(HEAT, LIGHT, MOISTURE): If container is exposed to high heat, 400°F (204°C) it can be pressurized and possibly rupture. MDI reacts slowly with water to form CO_2 gas. This gas can cause sealed containers to expand and possibly rupture.
PRECAUTIONS TO BE TAKEN
IN HANDLING AND STORING: Store in tightly closed containers to prevent moisture contamination. Do not reseal if contamination is suspected. Avoid contact with skin and eyes.

XI. SHIPPING DATA

TECHNICAL SHIPPING NAME..: Polymeric Diphenylmethane Diisocyanate
D.O.T. HAZARD
CLASSIFICATION.........: Non-regulated
FRT. CLASS BULK..........: Isocyanate
FRT. CLASS PKG...........: Chemicals NOI (Isocyanate) NMFC 60000
PRODUCT LABEL............: Mondur E-441 Label
REASON FOR ISSUE.........: Revision
APPROVED BY..............: J.H. Chapman/K.S. Booth
TITLE....................: Industrial Hygiene Polyurethane Division
DATE APPROVED............: 2/29/84

APPENDIX B

Product Information for

Reichhold IB-947 Resin

Reichhold Limited
4 Robert Speck Parkway, Suite 700
Mississauga, Ontario L4Z 1S1
Telex: 06-960282

IB-947 PHENOLIC POWDERED RESIN FOR THE MANUFACTURE OF WAFERBOARD/OSB

IB-947 is a fast curing, one-step powdered phenolic resin especially developed for the waferboard/OSB industry. It is most often used as a core resin in conjunction with a surface resin such as IB-948 or BD-003 but may be used in single resin systems throughout the panel.

POWDER PROPERTIES:

Colour: Pink
Form of Compound: Very Fine Powder
Screen Test (R.L. Test Method): 85% through 200 mesh
Storage Life: 3-4 months at 20°C

GENERAL SPECIFICATIONS:

Hot Plate Cure at 150°C:	10-20 seconds
Softening Point (Capillary):	85-95°C

STORAGE AND SHIPPING:

Resin being of a hygroscopic nature, it is recommended to store in cool dry place - temperature not exceeding 20°C. Shipped in multi-wall paper bags or tote bags.

SPECIAL HANDLING PRECAUTIONS:

Avoid prolonged contact with the skin. The use of goggles and dust masks are recommended when handling powdered resins.

If powder comes in contact with the skin, it should be washed off with warm water and soap. Cleanliness is important.

SAFETY BULLETIN:

Bulletins are available on request.

JUNE 1985

APPENDIX C

Sample Plots of Press Load, Displacement and Coreline Temperature

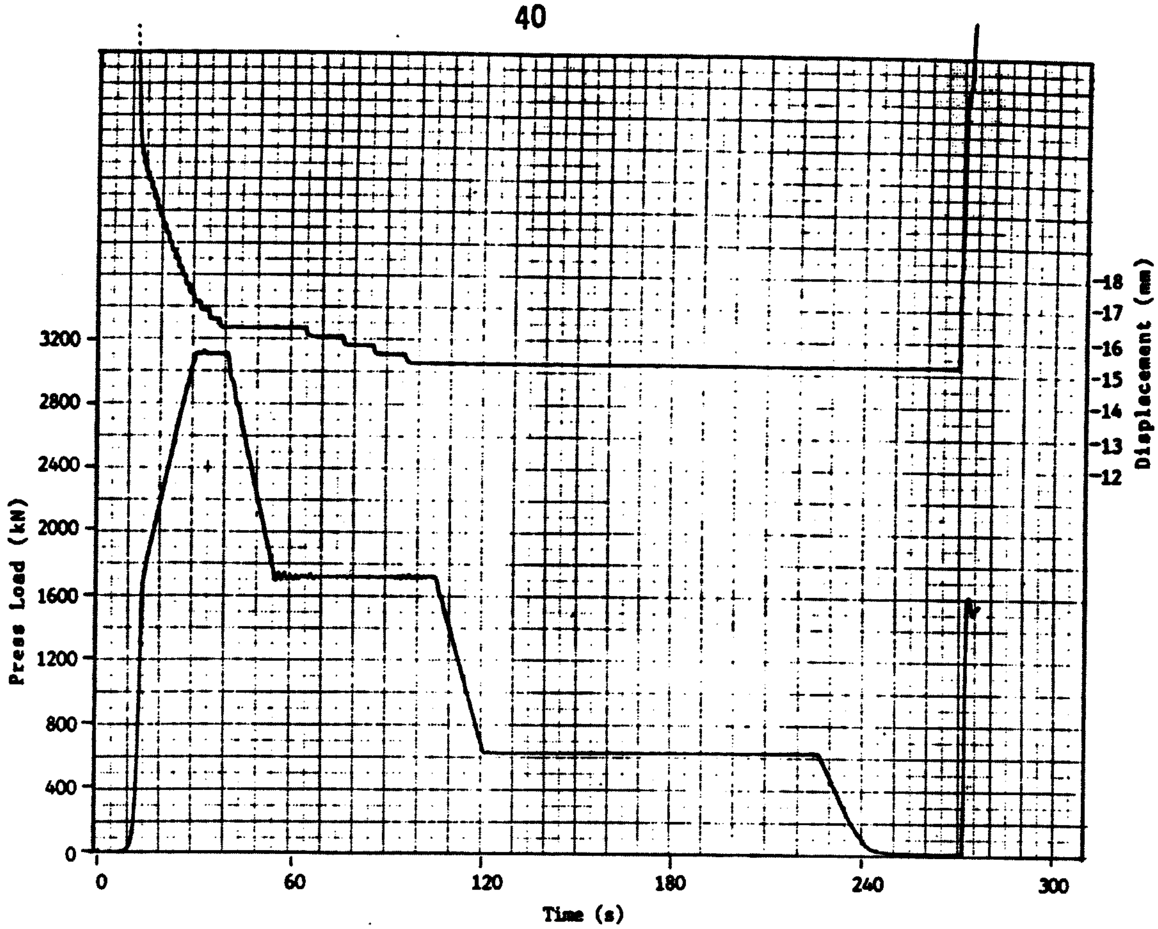

Figure C-1: Press Cycle and Displacement Profile for Panel No. 4 with 1.5% MDI Resin (MDII.5-4)

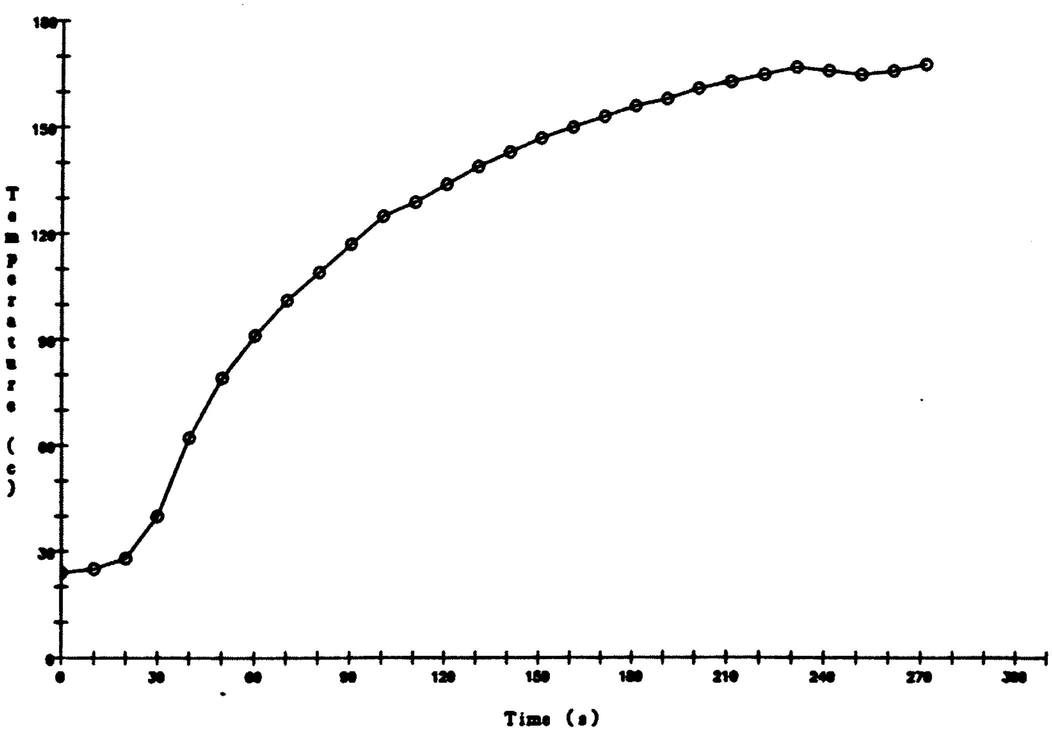

Figure C-2: Coreline Temperature Profile for Panel No. 4 with 1.5% MDI Resin (MDII.5-4)

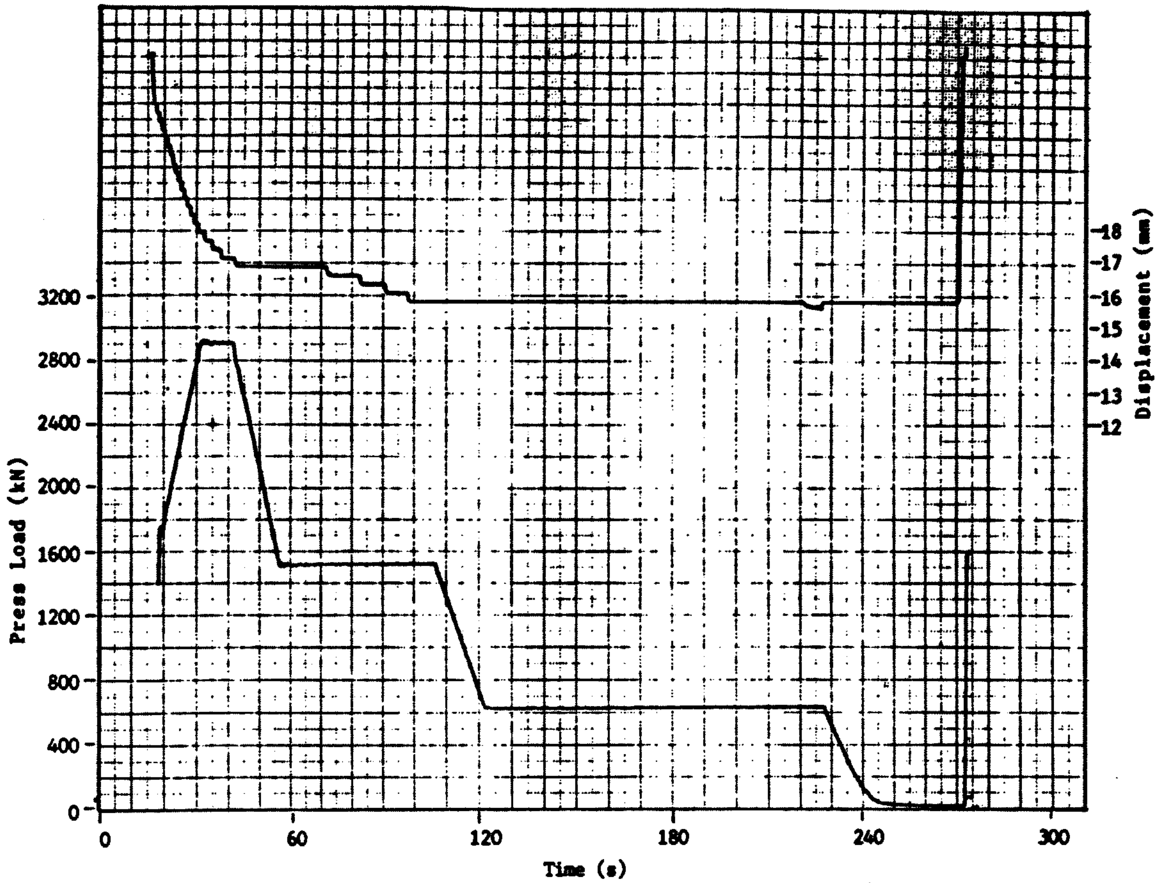

Figure C-3: Press Cycle and Displacement Profile for Panel No. 3 with 2.0% MDI Resin (MDI2.0-3)

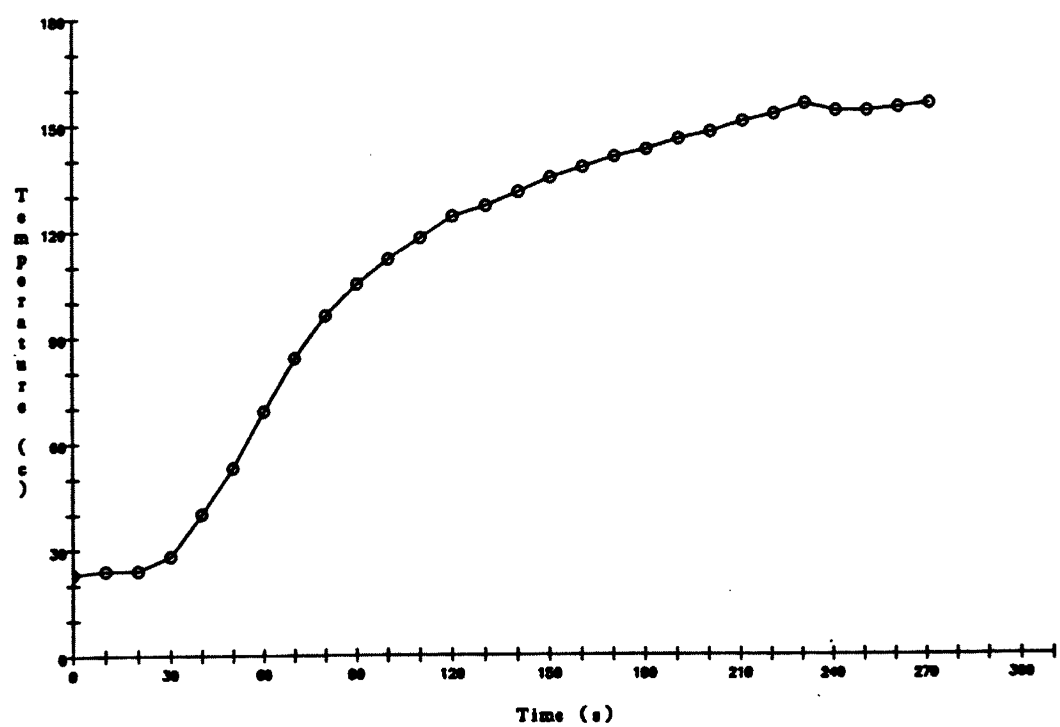

Figure C-4: Coreline Temperature Profile for Panel No. 3 with 2.0% MDI Resin (MDI2.0-3)

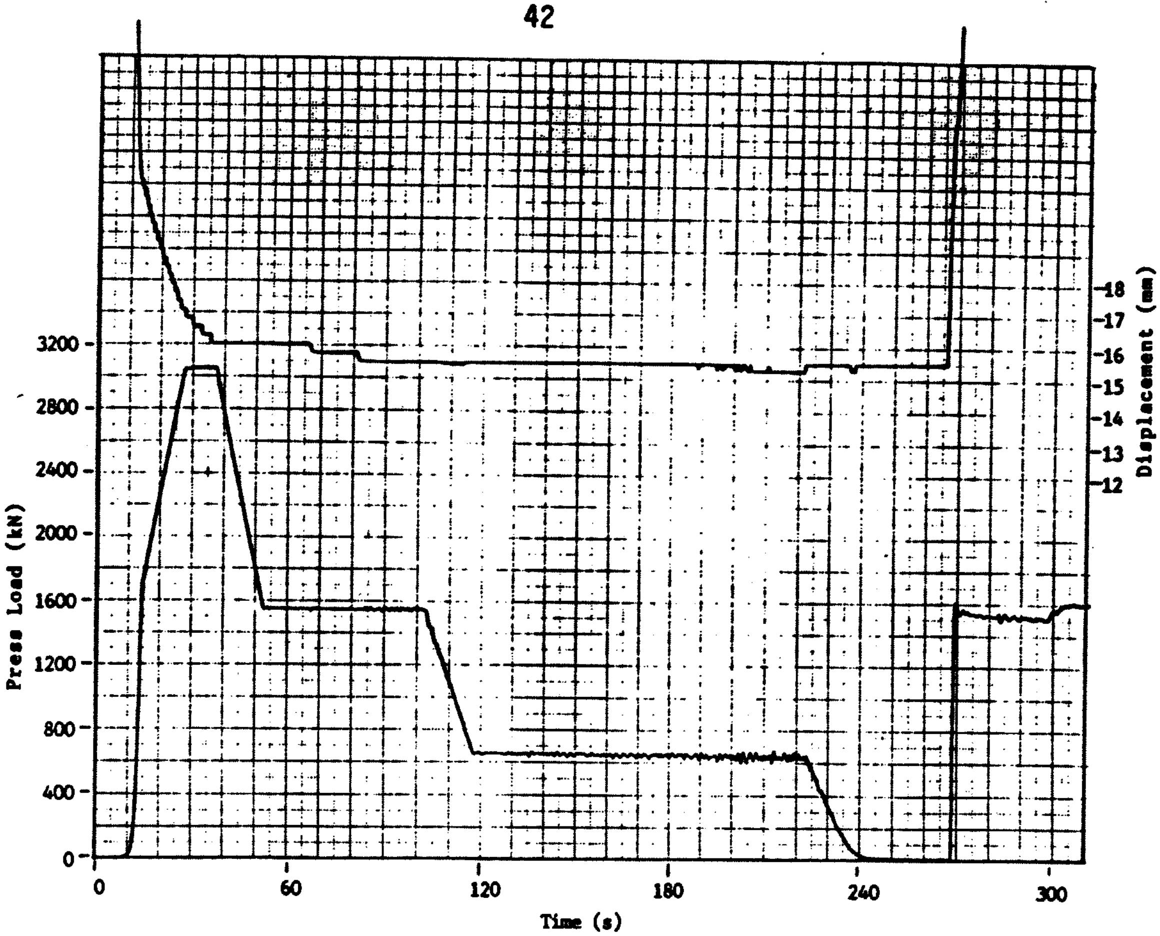

Figure C-5: Press Cycle and Displacement Profile for Panel No. 2 with 2.5% MDI Resin (MDI2.5-2)

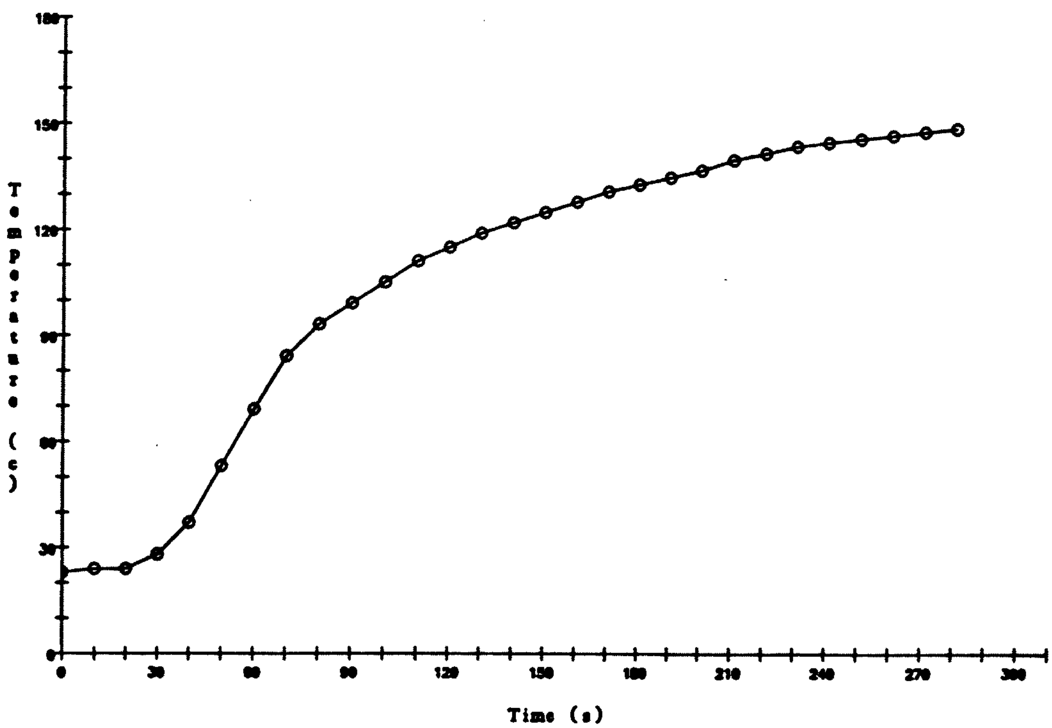

Figure C-6: Coreline Temperature Profile for Panel No. 2 with 2.5% MDI Resin (MDI2.5-2)

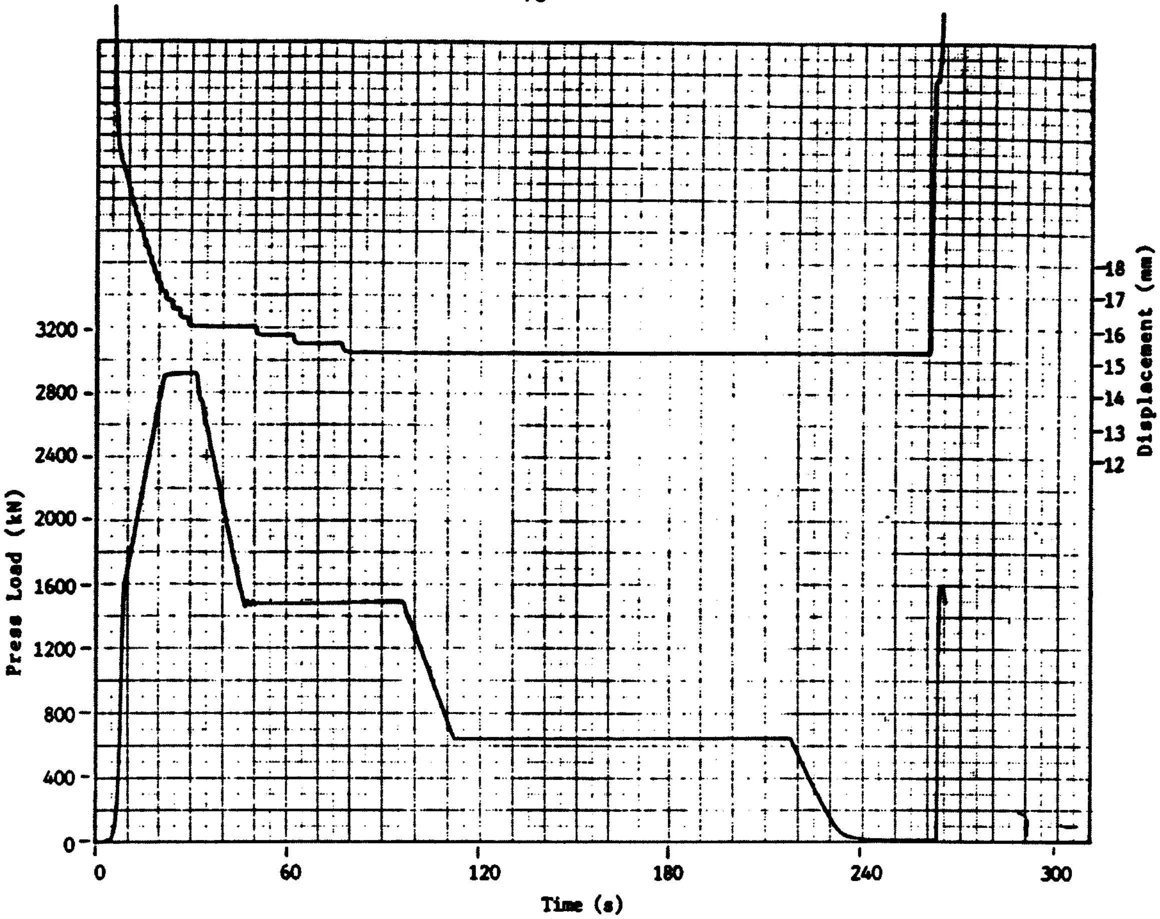

Figure C-7: Press Cycle and Displacement Profile for Control Panel No. 4 with 2.5% PF Resin (PF-4)

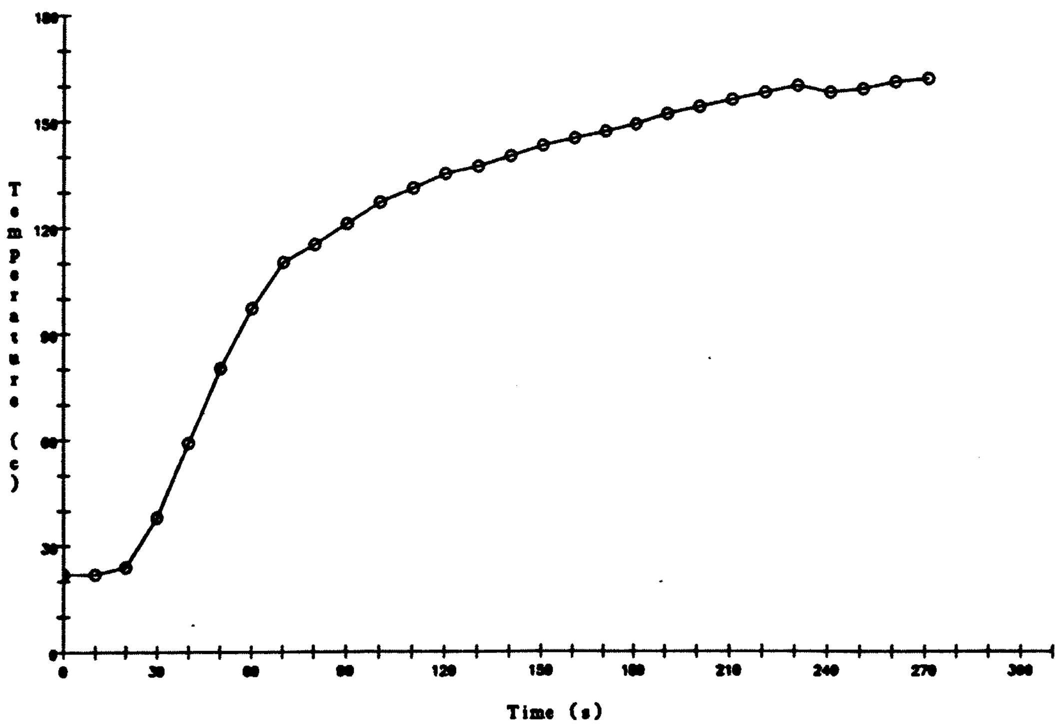

Figure C-8: Coreline Temperature Profile for Control Panel No. 4 with 2.5% PF Resin (PF-4)

APPENDIX D

Test Results for Panels Having

1.5% Polymeric MDI Binder

Table D-1

SUMMARY TABLE
GRADE PROPERTIES
(CAN3-0437.1-M85)

Client: Alberta Research Council
Test Date: March 30, 1987
Proj.Ref.: 303221

Test Material: Waferboard w/1.5% Iso Resin
Nom. Thickness: 11.1 mm
Conditioning: As per test requirements

	Units	CAN3-0437 R-1 Req.	Dir'n	MDI Panel Number 1.5-1	1.5-2	1.5-3	1.5-4	3 Panel Avg.
Modulus of rupture	MPa	17.2 17.2	Para Perp	30.9 29.3	- -	27.3 30.8	29.4 30.5	29.2 30.2
Modulus of elasticity	MPa	3100 3100	Para Perp	5200 5000	- -	5100 4900	5200 4800	5170 4900
Internal bond	MPa	0.345		0.438	-	0.569	0.489	0.499
Bond durability - MOR after 2 h boil	MPa	8.6 8.6	Para Perp	14.0 11.8	- -	15.0 13.1	14.4 12.1	14.5 12.3
Thickness swell - 24 h soak - 12.7 mm or thinner	%	25		14	-	14	11	13
Linear expansion - oven dry to saturated	%	0.40 0.40	Para Perp	0.25 0.22	- -	0.33 0.34	0.24 0.19	0.28 0.25
General								
Moisture Content Density	% kg/cu.m	8 max. None		3 629	- -	2 664	3 659	3 651

ALBERTA RESEARCH COUNCIL
FOREST PRODUCTS LABORATORY

Table D-2
Moisture Content and Density
(CAN3-0437.1-M85)

Client: ARC
Test Date: March 26,1987
Proj. Ref.: 303221

Test Material: 1.5% Iso.
Nom. Thickness: 11.1 mm
Conditioning: Oven Dry& at Test

Panel No.	Sample No.	Length	Width	Thick-ness	TEST Weight	O.D. Weight	M.C.	Avg. M.C.	Density at Test	Avg. Density at Test
		mm	mm	mm	g	g	%	%	kg/cu.m	kg/cu.m
	1	75.0	75.0	11.50	39.4	38.1	3		609	
1.5-1	2	75.0	75.0	11.25	41.1	39.9	3	3	649	629
	1	75.0	75.0	10.65	38.4	37.7	2		641	
1.5-3	2	75.0	75.0	10.45	40.4	39.8	2	2	687	664
	1	75.0	75.0	10.60	39.3	38.3	3		659	
1.5-4	2	75.0	75.0	10.70	39.7	38.8	2	3	660	659
No.		6	6	6	6	6	6	3	6	3
Avg.		75.0	75.0	10.86	39.7	38.8	3	3	651	651

ALBERTA RESEARCH COUNCIL

FOREST PRODUCTS LABORATORY

Table D-3

MOR & MOE DRY-Parallel
(CAN3-0437.1-M85)

Client:	ARC	Test Material:	1.5% Iso.
Test Date:	March 25,1987	Nom. Thickness:	11.1 mm
Proj.Ref.:	303221	Conditioning:	As Received
		Span:	266.0 mm

Panel No.	Sample No.	Thick-ness	Width	Max. Load	MOE	Avg. MOE	MOR	Avg. MOR
		mm	mm	N	MPa	MPa	MPa	MPa
	1	11.28	74.8	766	5300		32.1	
1.5-1	2	11.26	74.8	824	5200	5200	34.7	30.9
	3	11.16	74.8	606	5000		26.0	
	1	10.80	74.8	725	5900		33.2	
1.5-3	2	10.68	74.6	618	5200	5100	29.0	27.3
	3	10.68	74.6	419	4300		19.6	
	1	10.78	74.6	590	5200		27.2	
1.5-4	2	10.70	74.6	622	5500	5200	29.1	29.4
	3	10.70	74.8	687	5000		32.0	
No.		9	9	9	9	3	9	3
Avg.		10.89	74.7	651	5170	5170	29.2	29.2

ALBERTA RESEARCH COUNCIL

FOREST PRODUCTS LABORATORY

Table D-4

MOR & MOE DRY-Perpendicular
(CAN3-0437.1-M85)

Client:	ARC	Test Material:	1.5% Iso.
Test Date:	March 25,1987	Nom. Thickness:	11.1 mm
Proj.Ref.:	303221	Conditioning:	As Received
		Span:	266.0 mm

Panel No.	Sample No.	Thick-ness	Width	Max. Load	MOE	Avg. MOE	MOR	Avg. MOR
		mm	mm	N	MPa	MPa	MPa	MPa
	4	11.14	74.8	475	3900		20.4	
1.5-1	5	11.20	74.8	742	4900	5000	31.6	29.3
	6	11.42	74.6	879	6300		36.0	
	4	10.62	74.8	640	4600		30.3	
1.5-3	5	10.34	74.8	609	5000	4900	30.4	30.8
	6	10.54	74.8	662	5000		31.8	
	4	10.78	74.8	745	5500		34.2	
1.5-4	5	10.64	74.8	441	3600	4800	20.8	30.5
	6	10.68	74.8	781	5400		36.5	
No.		9	9	9	9	3	9	3
Avg.		10.82	74.8	664	4900	4900	30.2	30.2

ALBERTA RESEARCH COUNCIL

FOREST PRODUCTS LABORATORY

Table D-5
Internal Bond
(CAN3-0437.1-M85)

Client: ARC
Test Date: March 26, 1987
Proj.Ref.: 303221

Test Material: 1.5% Iso.
Nom. Thicknes: 11.1 mm
Conditioning: As Received

Panel No.	Sample Number	Sample Length	Sample Width	Maximum Load	Internal Bond Strength	Average For Panel
		mm	mm	N	MPa	MPa
1.5-1	1	50.4	49.6	1069	0.428	0.438
	2	49.6	50.2	722	0.290	
	3	50.0	49.6	725	0.292	
	4	50.2	49.4	1490	0.601	
	5	49.6	50.4	1067	0.427	
	6	50.0	49.4	1452	0.588	
1.5-3	1	49.4	50.0	1267	0.513	0.569
	2	49.4	50.4	1466	0.589	
	3	49.6	50.2	1409	0.566	
	4	49.6	50.0	1191	0.480	
	5	49.6	50.0	1573	0.634	
	6	49.4	50.0	1564	0.633	
1.5-4	1	49.6	50.0	1388	0.560	0.489
	2	49.6	50.0	1252	0.505	
	3	49.4	50.2	1282	0.517	
	4	49.6	50.0	870	0.351	
	5	49.6	50.0	1005	0.405	
	6	49.6	49.8	1478	0.598	
No.		18	18	18	18	3
Avg.		49.7	50.0	1240	0.499	0.499

ALBERTA RESEARCH COUNCIL

FOREST PRODUCTS LABORATORY

Table D-6

Bond Durability-MOR after 2 Hour Boil-Parallel
(CAN3-0437.1-M85)

Client: ARC
Test Date: March 25,1987
Proj.Ref.: 303221
Span: 266 mm

Test Material: 1.5% Iso.
Nom. Thickness: 11.1 mm
Conditioning: 2 Hour Boil

Panel No.	Sample No.	Sample Thickness	Sample Width	Maximum Load	MOR	Average MOR for Panel
		mm	mm	N	MPa	MPa
	1	11.22	74.6	337	14.3	
1.5-1	2	11.16	74.6	322	13.8	14.0
	3	11.24	74.8	328	13.8	
	1	10.78	74.6	366	16.8	
1.5-3	2	10.64	74.8	252	11.9	15.0
	3	10.66	74.8	345	16.2	
	1	10.68	74.8	232	10.8	
1.5-4	2	10.60	74.8	289	13.7	14.4
	3	10.76	74.6	403	18.6	
No.		9	9	9	9	3
Avg.		10.9	74.7	319	14.5	14.5

ALBERTA RESEARCH COUNCIL

FOREST PRODUCTS LABORATORY

Table D-7

Bond Durability-MOR after 2 Hour Boil-Perpendicular (CAN3-0437.1-M85)

Client: ARC
Test Date: March 25,1987
Proj.Ref.: 303221
Span: 266 mm

Test Material: 1.5% Iso.
Nom. Thickness: 11.1 mm
Conditioning: 2 Hour Boil

Panel No.	Sample No.	Sample Thickness	Sample Width	Maximum Load	MOR	Average MOR for Panel
		mm	mm	N	MPa	MPa
	4	11.14	74.8	342	14.7	
1.5-1	5	11.16	74.8	192	8.2	11.8
	6	11.32	74.8	297	12.4	
	4	10.72	74.8	328	15.2	
1.5-3	5	10.52	74.8	274	13.2	13.1
	6	10.56	74.6	225	10.8	
	4	11.00	74.8	295	13.0	
1.5-4	5	10.78	74.8	297	13.6	12.1
	6	10.68	74.8	206	9.6	
No.		9	9	9	9	3
Avg.		10.88	74.8	273	12.3	12.3

ALBERTA RESEARCH COUNCIL

FOREST PRODUCTS LABORATORY

Table D-8

Thickness Swell
(CAN3-0437.1-M85)

Client:	ARC	Test Material:	1.5% Iso.
Test Date:	March 23,1987	Nom. Thickness:	11.1 mm
Proj. Ref.:	303221	Conditioning:	24 hr. Soak

Panel No.	Sample No.	Dry Thickness Position 1	2	3	4	Wet Thickness Position 1	2	3	4	Average Thick. Swell
		mm	mm	mm	mm	mm	mm	mm	mm	%
1.5-1	1	11.50	11.40	11.60	11.60	13.25	12.95	13.30	13.50	14
	2	11.20	11.20	11.15	11.25	12.60	13.00	12.75	12.65	
1.5-3	1	10.65	10.70	10.75	11.00	12.00	11.90	12.00	12.60	14
	2	10.75	10.70	10.55	10.60	12.45	12.85	11.90	12.20	
1.5-4	1	10.60	10.60	10.60	10.70	11.85	11.70	11.90	11.75	11
	2	10.70	10.65	10.65	10.60	11.85	11.95	11.75	11.95	
No.		6	6	6	6	6	6	6	6	3
Avg.		10.90	10.88	10.88	10.96	12.33	12.39	12.27	12.44	13

ALBERTA RESEARCH COUNCIL

FOREST PRODUCTS LABORATORY

Table D-9

Linear Expansion-Oven Dry to Saturated
(CAN3-0437.1-M85)

Client: ARC
Test Date: March 30, 1987
Proj. Ref.: 303221

Test Material: 1.5 % Iso.
Nom. Thickness: 11.1 mm
Conditioning: OD to Saturated

Panel No.	Sample No.		Oven Dry Gauge Length		Vac.-Pressure Gauge Length		Linear Expansion		Avg. Linear Expansion	
	Par.	Perp.	Par.	Perp.	Par.	Perp.	Par.	Perp.	Par.	Perp.
			mm	mm	mm	mm	%	%	%	%
1.5-1	1	3	235.80	235.65	236.55	236.05	0.32	0.17	0.25	0.22
	2	4	236.50	236.25	236.95	236.90	0.19	0.28		
1.5-3	1	3	235.45	235.40	236.35	236.30	0.38	0.38	0.33	0.34
	2	4	236.10	236.05	236.75	236.75	0.28	0.30		
1.5-4	1	3	236.40	235.90	237.05	236.40	0.27	0.21	0.24	0.19
	2	4	236.25	236.05	236.75	236.45	0.21	0.17		
No.			6	6	6	7	6	6	3	3
Avg.			236.08	235.88	236.73	202.69	0.28	0.25	0.28	0.25

ALBERTA RESEARCH COUNCIL

FOREST PRODUCTS LABORATORY

Appendix E

Test Results for Panels Having 2.0% Polymeric MDI Binder

Table E-1
SUMMARY TABLE
GRADE PROPERTIES
(CAN3-0437.1-M85)

Client: Alberta Research Council
Test Date: March 30, 1987
Proj.Ref.: 303221

Test Material: Waferboard w/2.0% Iso Resin
Nom. Thickness: 11.1 mm
Conditioning: As per test requirements

	Units	CAN3-0437 R-1 Req.	Dir'n	MDI Panel Number 2.0-1	2.0-2	2.0-3	2.0-4	3 Panel Avg.
Modulus of rupture	MPa	17.2	Para	35.6	39.4	-	32.6	35.9
		17.2	Perp	31.6	33.5	-	31.6	32.2
Modulus of elasticity	MPa	3100	Para	5400	5900	-	5300	5530
		3100	Perp	5200	5700	-	5100	5330
Internal bond	MPa	0.345		0.622	0.699	-	0.616	0.646
Bond durability - MOR after 2 h boil	MPa	8.6	Para	19.7	15.7	-	15.9	17.1
		8.6	Perp	18.3	16.8	-	16.9	17.3
Thickness swell - 24 h soak - 12.7 mm or thinner	%	25		13	13	-	13	13
Linear expansion - oven dry to saturated	%	0.40	Para	0.24	0.25	-	0.21	0.24
		0.40	Perp	0.27	0.22	-	0.32	0.27
General								
Moisture Content	%	8 max.		3	3	-	3	3
Density	kg/cu.m	None		656	681	-	696	678

ALBERTA RESEARCH COUNCIL
FOREST PRODUCTS LABORATORY

Table E-2

Moisture Content and Density
(CAN3-0437.1-M85)

Client: ARC
Test Date: March 26,1987
Proj. Ref.: 303221

Test Material: 2.0% Iso.
Nom. Thickness: 11.1 mm
Conditioning: Oven Dry& at Test

Panel No.	Sample No.	Length	Width	Thick-ness	TEST Weight	O.D. Weight	M.C.	Avg. M.C.	Density at Test	Avg. Density at Test
		mm	mm	mm	g	g	%	%	kg/cu.m	kg/cu.m
	1	75.5	75.5	10.85	37.7	36.6	3		610	
2.0-1	2	75.5	75.5	10.75	43.0	42.2	2	3	702	656
	1	75.5	75.5	10.80	44.3	43.2	3		720	
2.0-2	2	75.0	75.0	10.75	38.9	38.0	2	3	643	681
	1	75.5	75.0	10.90	43.9	42.5	3		711	
2.0-4	2	74.5	74.5	10.90	41.2	40.1	3	3	681	696
No.		6	6	6	6	6	6	3	6	3
Avg.		75.3	75.2	10.83	41.5	40.4	3	3	678	678

ALBERTA RESEARCH COUNCIL

FOREST PRODUCTS LABORATORY

Table E-3

Internal Bond
(CAN3-0437.1-M85)

Client: ARC
Test Date: March 26,1987
Proj.Ref.: 303221

Test Material: 2.0% Iso.
Nom. Thicknes: 11.1 mm
Conditioning: As Received

Panel No.	Sample Number	Sample Length	Sample Width	Maximum Load	Internal Bond Strength	Average For Panel
		mm	mm	N	MPa	MPa
	1	50.0	49.6	1317	0.531	
	2	50.0	49.6	1510	0.609	
2.0-1	3	50.0	49.6	1581	0.638	0.622
	4	50.0	49.6	1603	0.646	
	5	49.8	49.4	1754	0.713	
	6	50.0	49.4	1472	0.596	
	1	50.0	49.6	1838	0.741	
	2	49.8	49.6	1770	0.717	
2.0-2	3	49.8	49.4	1350	0.549	0.699
	4	50.0	49.6	1823	0.735	
	5	49.8	49.6	1747	0.707	
	6	49.8	49.8	1855	0.748	
	1	49.6	50.0	1354	0.546	
	2	49.6	50.0	1548	0.624	
2.0-4	3	49.6	50.2	1243	0.499	0.616
	4	49.8	49.6	1442	0.584	
	5	49.6	49.8	1625	0.658	
	6	50.0	49.6	1940	0.782	
No.		18	18	18	18	3
Avg.		49.8	49.7	1600	0.646	0.646

ALBERTA RESEARCH COUNCIL

FOREST PRODUCTS LABORATORY

Table E-4

MOR & MOE DRY-Parallel
(CAN3-0437.1-M85)

Client: ARC
Test Date: March 25,1987
Proj.Ref.: 303221

Test Material: 2.0% Iso.
Nom. Thickness: 11.1 mm
Conditioning: As Received
Span: 266.0 mm

Panel No.	Sample No.	Thick-ness	Width	Max. Load	MOE	Avg. MOE	MOR	Avg. MOR
		mm	mm	N	MPa	MPa	MPa	MPa
	1	10.90	75.0	1012	7300		45.3	
2.0-1	2	10.70	75.0	625	4000	5400	29.0	35.6
	3	10.76	75.2	705	5000		32.3	
	1	10.94	74.8	1123	6500		50.1	
2.0-2	2	10.74	75.2	652	5200	5900	30.0	39.4
	3	10.78	74.8	833	6100		38.2	
	1	11.10	75.0	786	6100		33.9	
2.0-4	2	10.92	75.4	643	5100	5300	28.5	32.6
	3	10.92	75.2	795	4800		35.4	
No.		9	9	9	9	3	9	3
Avg.		10.86	75.1	797	5530	5530	35.9	35.9

ALBERTA RESEARCH COUNCIL

FOREST PRODUCTS LABORATORY

Table E-5

MOR & MOE DRY-Perpendicular
(CAN3-0437.1-M85)

Client: ARC
Test Date: March 25,1987
Proj.Ref.: 303221

Test Material: 2.0% Iso.
Nom. Thickness: 11.1 mm
Conditioning: As Received
Span: 266.0 mm

Panel No.	Sample No.	Thickness	Width	Max. Load	MOE	Avg. MOE	MOR	Avg. MOR
		mm	mm	N	MPa	MPa	MPa	MPa
	4	10.82	75.2	809	5500		36.7	
2.0-1	5	10.66	75.2	676	5500	5200	31.6	31.6
	6	10.68	75.2	571	4700		26.6	
	4	10.96	75.0	755	5600		33.4	
2.0-2	5	10.88	74.6	701	5900	5700	31.7	33.5
	6	10.84	74.8	782	5700		35.5	
	4	11.12	74.6	816	5400		35.3	
2.0-4	5	11.00	74.6	767	5300	5100	33.9	31.6
	6	11.00	74.6	578	4700		25.5	
No.		9	9	9	9	3	9	3
Avg.		10.88	74.9	717	5330	5330	32.2	32.2

ALBERTA RESEARCH COUNCIL

FOREST PRODUCTS LABORATORY

Table E-6

Bond Durability-MOR after 2 Hour Boil-Parallel
(CAN3-0437.1-M85)

Client: ARC
Test Date: March 25,1987
Proj.Ref.: 303221
Span: 266 mm

Test Material: 2.0% Iso.
Nom. Thickness: 11.1 mm
Conditioning: 2 Hour Boil

Panel No.	Sample No.	Sample Thickness	Sample Width	Maximum Load	MOR	Average MOR for Panel
		mm	mm	N	MPa	MPa
	1	10.62	75.2	430	20.2	
2.0-1	2	10.76	75.2	431	19.8	19.7
	3	10.80	75.2	418	19.0	
	1	10.78	75.2	382	17.4	
2.0-2	2	10.74	75.2	329	15.1	15.7
	3	10.86	75.2	321	14.4	
	1	10.96	75.0	390	17.3	
2.0-4	2	10.96	75.2	364	16.1	15.9
	3	11.10	75.0	330	14.2	
No.		9	9	9	9	3
Avg.		10.8	75.2	377	17.1	17.1

ALBERTA RESEARCH COUNCIL

FOREST PRODUCTS LABORATORY

Table E-7

Bond Durability-MOR after 2 Hour Boil-Perpendicular
(CAN3-0437.1-M85)

Client: ARC
Test Date: March 25,1987
Proj.Ref.: 303221
Span: 266 mm

Test Material: 2.0% Iso.
Nom. Thickness: 11.1 mm
Conditioning: 2 Hour Boil

Panel No.	Sample No.	Sample Thickness	Sample Width	Maximum Load	MOR	Average MOR for Panel
		mm	mm	N	MPa	MPa
	4	10.98	75.2	474	20.9	
2.0-1	5	10.74	75.2	379	17.4	18.3
	6	10.70	75.2	357	16.5	
	4	11.18	74.8	370	15.8	
2.0-2	5	10.90	74.8	375	16.8	16.8
	6	10.84	74.8	390	17.7	
	4	11.30	74.6	374	15.7	
2.0-4	5	11.06	74.6	345	15.1	16.9
	6	10.98	74.6	450	20.0	
No.		9	9	9	9	3
Avg.		10.96	74.9	390	17.3	17.3

ALBERTA RESEARCH COUNCIL

FOREST PRODUCTS LABORATORY

Table E-8

Thickness Swell
(CAN3-0437.1-M85)

Client: ARC
Test Date: March 23,1987
Proj. Ref.: 303221

Test Material: 2.0% Iso.
Nom. Thickness: 11.1 mm
Conditioning: 24 hr. Soak

Panel No.	Sample No.	Dry Thickness Position 1	Dry Thickness Position 2	Dry Thickness Position 3	Dry Thickness Position 4	Wet Thickness Position 1	Wet Thickness Position 2	Wet Thickness Position 3	Wet Thickness Position 4	Average Thick. Swell
		mm	mm	mm	mm	mm	mm	mm	mm	%
2.0-1	1	10.75	10.75	10.65	10.75	12.05	11.95	12.05	12.60	13
	2	10.75	10.75	10.75	10.70	11.95	12.05	11.70	12.45	
2.0-2	1	10.80	10.75	10.75	10.70	11.90	12.20	12.20	12.25	13
	2	10.75	10.80	10.75	10.75	12.30	12.00	12.20	12.00	
2.0-4	1	10.85	10.85	10.90	10.85	12.95	12.40	12.25	12.15	13
	2	10.95	10.85	10.85	10.85	12.10	12.05	12.00	12.55	
No.		6	6	6	6	6	6	6	6	3
Avg.		10.81	10.79	10.78	10.77	12.21	12.11	12.07	12.33	13

ALBERTA RESEARCH COUNCIL

FOREST PRODUCTS LABORATORY

Table E-9

Linear Expansion-Oven Dry to Saturated
(CAN3-0437.1-M85)

Client: ARC
Test Date: March 30, 1987
Proj. Ref.: 303221

Test Material: 2.0 % Iso.
Nom. Thickness: 11.1 mm
Conditioning: OD to Saturated

Panel No.	Sample No.		Oven Dry Gauge Length		Vac.-Pressure Gauge Length		Linear Expansion		Avg. Linear Expansion	
	Par.	Perp.	Par.	Perp.	Par.	Perp.	Par.	Perp.	Par.	Perp.
			mm	mm	mm	mm	%	%	%	%
2.0-1	1	3	236.20	234.75	236.95	235.25	0.32	0.21	0.24	0.27
	2	4	236.50	236.10	236.90	236.85	0.17	0.32		
2.0-2	1	3	235.00	234.20	235.65	235.00	0.28	0.34	0.25	0.22
	2	4	237.35	236.50	237.90	236.75	0.23	0.11		
2.0-4	1	3	236.40	235.70	236.80	236.50	0.17	0.34	0.21	0.32
	2	4	235.90	234.75	236.50	235.45	0.25	0.30		
No.			6	6	6	7	6	6	3	3
Avg.			236.23	235.33	236.78	202.26	0.24	0.27	0.24	0.27

ALBERTA RESEARCH COUNCIL

FOREST PRODUCTS LABORATORY

APPENDIX F

Test Results for Panels Having

2.5% Polymeric MDI Binder

Table F-1

SUMMARY TABLE
GRADE PROPERTIES
(CAN3-0437.1-M85)

Client: Alberta Research Council
Test Date: March 30, 1987
Proj.Ref.: 303221

Test Material: Waferboard w/2.5% Iso Resin
Nom. Thickness: 11.1 mm
Conditioning: As per test requirements

	Units	CAN3-0437 R-1 Req.	Dir'n	MDI Panel Number 2.5-1	2.5-2	2.5-3	2.5-4	3 Panel Avg.
Modulus of rupture	MPa	17.2 17.2	Para Perp	38.2 32.2	35.7 35.3	- -	38.2 30.4	37.4 32.6
Modulus of elasticity	MPa	3100 3100	Para Perp	6600 4800	5500 5100	- -	6500 5000	6200 4970
Internal bond	MPa	0.345		0.593	0.613	-	0.707	0.637
Bond durability - MOR after 2 h boil	MPa	8.6 8.6	Para Perp	16.5 18.0	18.8 16.9	- -	15.7 15.3	17.0 16.7
Thickness swell - 24 h soak - 12.7 mm or thinner	%	25		9	10	-	11	10
Linear expansion - oven dry to saturated	%	0.40 0.40	Para Perp	0.22 0.25	0.30 0.14	- -	0.31 0.33	0.28 0.24
General								
Moisture Content Density	% kg/cu.m	8 max. None		3 706	3 675	- -	4 638	3 673

ALBERTA RESEARCH COUNCIL
FOREST PRODUCTS LABORATORY

Table F-2
Moisture Content and Density
(CAN3-0437.1-M85)

Client: ARC
Test Date: March 26,1987
Proj. Ref.: 303221

Test Material: 2.5% Iso.
Nom. Thickness: 11.1 mm
Conditioning: Oven Dry& at Test

Panel No.	Sample No.	Length	Width	Thick-ness	TEST Weight	O.D. Weight	M.C.	Avg. M.C.	Density at Test	Avg. Density at Test
		mm	mm	mm	g	g	%	%	kg/cu.m	kg/cu.m
	1	75.5	75.5	10.95	45.5	44.3	3		729	
2.5-1	2	75.0	75.0	10.95	42.1	41.2	2	3	684	706
	1	75.5	75.5	10.75	38.7	37.9	2		632	
2.5-2	2	75.0	75.0	10.95	44.2	42.9	3	3	718	675
	1	75.5	75.5	10.95	38.2	36.8	4		612	
2.5-4	2	75.0	75.0	10.85	40.5	39.5	3	4	664	638
No.		6	6	6	6	6	6	3	6	3
Avg.		75.3	75.3	10.90	41.5	40.4	3	3	673	673

ALBERTA RESEARCH COUNCIL

FOREST PRODUCTS LABORATORY

Table F-3

MOR & MOE DRY-Parallel
(CAN3-0437.1-M85)

Client: ARC
Test Date: March 25,1987
Proj.Ref.: 303221

Test Material: 2.5% Iso.
Nom. Thickness: 11.1 mm
Conditioning: As Received
Span: 266.0 mm

Panel No.	Sample No.	Thick-ness	Width	Max. Load	MOE	Avg. MOE	MOR	Avg. MOR
		mm	mm	N	MPa	MPa	MPa	MPa
	1	11.12	75.2	856	8000		36.7	
2.5-1	2	11.02	75.2	885	5800	6600	38.7	38.2
	3	10.94	75.2	887	5900		39.3	
	1	11.06	74.6	921	6200		40.3	
2.5-2	2	10.86	74.6	759	5300	5500	34.4	35.7
	3	10.94	74.6	725	4900		32.4	
	1	11.12	75.2	852	8100		36.6	
2.5-4	2	11.00	75.4	852	5600	6500	37.3	38.2
	3	11.04	75.4	941	5800		40.9	
No.		9	9	9	9	3	9	3
Avg.		11.01	75.0	853	6200	6200	37.4	37.4

ALBERTA RESEARCH COUNCIL

FOREST PRODUCTS LABORATORY

Table F-4

MOR & MOE DRY-Perpendicular
(CAN3-0437.1-M85)

Client:	ARC	Test Material:	2.5% Iso.
Test Date:	March 25,1987	Nom. Thickness:	11.1 mm
Proj.Ref.:	303221	Conditioning:	As Received
		Span:	266.0 mm

Panel No.	Sample No.	Thickness	Width	Max. Load	MOE	Avg. MOE	MOR	Avg. MOR
		mm	mm	N	MPa	MPa	MPa	MPa
	4	11.06	75.0	927	5100		40.3	
2.5-1	5	10.98	75.2	792	5100	4800	34.9	33.2
	6	10.94	75.2	548	4200		24.3	
	4	10.94	75.2	902	5400		40.0	
2.5-2	5	10.78	75.0	595	4800	5100	27.2	35.3
	6	10.80	75.0	849	5000		38.7	
	4	10.96	75.2	707	5400		31.2	
2.5-4	5	10.88	75.2	665	4800	5000	29.8	30.4
	6	10.90	75.0	676	4800		30.3	
No.		9	9	9	9	3	9	3
Avg.		10.92	75.1	740	4970	4970	33.0	33.0

ALBERTA RESEARCH COUNCIL

FOREST PRODUCTS LABORATORY

Table F-5
Internal Bond
(CAN3-0437.1-M85)

Client: ARC
Test Date: March 26, 1987
Proj.Ref.: 303221

Test Material: 2.5% Iso.
Nom. Thicknes: 11.1 mm
Conditioning: As Received

Panel No.	Sample Number	Sample Length	Sample Width	Maximum Load	Internal Bond Strength	Average For Panel
		mm	mm	N	MPa	MPa
	1	50.0	49.4	1550	0.628	
	2	50.0	49.6	1359	0.548	
2.5-1	3	50.2	49.6	1542	0.619	0.593
	4	50.0	49.4	1660	0.672	
	5	50.2	49.6	1217	0.489	
	6	50.0	49.6	1497	0.604	
	1	49.6	50.0	1672	0.674	
	2	49.6	50.4	1988	0.795	
2.5-2	3	49.6	50.4	726	0.290	0.613
	4	49.6	50.4	1514	0.606	
	5	49.8	50.4	1309	0.522	
	6	49.6	50.2	1962	0.788	
	1	49.4	50.0	1977	0.800	
	2	49.6	50.0	1903	0.767	
2.5-4	3	49.6	50.2	2115	0.849	0.707
	4	50.4	49.8	1285	0.512	
	5	50.2	49.4	1430	0.577	
	6	49.6	50.2	1827	0.734	
No.		18	18	18	18	3
Avg.		49.8	49.9	1590	0.637	0.637

ALBERTA RESEARCH COUNCIL

FOREST PRODUCTS LABORATORY

Table F-6

Bond Durability-MOR after 2 Hour Boil-Parallel
(CAN3-0437.1-M85)

Client: ARC
Test Date: March 25,1987
Proj.Ref.: 303221
Span: 266 mm

Test Material: 2.5% Iso.
Nom. Thickness: 11.1 mm
Conditioning: 2 Hour Boil

Panel No.	Sample No.	Sample Thickness	Sample Width	Maximum Load	MOR	Average MOR for Panel
		mm	mm	N	MPa	MPa
	1	10.98	75.2	412	18.1	
2.5-1	2	10.98	75.2	392	17.3	16.5
	3	11.04	75.0	323	14.1	
	1	10.92	74.6	341	15.3	
2.5-2	2	10.88	74.6	547	24.7	18.8
	3	10.88	74.6	362	16.4	
	1	11.06	75.4	380	16.4	
2.5-4	2	11.00	75.4	352	15.4	15.7
	3	11.04	75.4	353	15.3	
No.		9	9	9	9	3
Avg.		11.0	75.0	385	17.0	17.0

ALBERTA RESEARCH COUNCIL

FOREST PRODUCTS LABORATORY

Table F-7

Bond Durability-MOR after 2 Hour Boil-Perpendicular (CAN3-0437.1-M85)

Client: ARC
Test Date: March 25,1987
Proj.Ref.: 303221
Span: 266 mm

Test Material: 2.5% Iso.
Nom. Thickness: 11.1 mm
Conditioning: 2 Hour Boil

Panel No.	Sample No.	Sample Thickness	Sample Width	Maximum Load	MOR	Average MOR for Panel
		mm	mm	N	MPa	MPa
	4	11.28	74.8	574	24.1	
2.5-1	5	11.90	75.0	430	16.1	18.0
	6	10.94	75.0	311	13.8	
	4	11.16	75.0	368	15.7	
2.5-2	5	10.90	75.0	379	17.0	16.9
	6	10.70	75.0	387	18.0	
	4	11.16	75.0	436	18.6	
2.5-4	5	10.90	75.0	298	13.3	15.3
	6	10.90	75.0	312	14.0	
No.		9	9	9	9	3
Avg.		11.09	75.0	388	16.7	16.7

ALBERTA RESEARCH COUNCIL

FOREST PRODUCTS LABORATORY

Table F-8

Thickness Swell
(CAN3-O437.1-M85)

Client: ARC
Test Date: March 23,1987
Proj. Ref.: 303221

Test Material: 2.5% Iso.
Nom. Thickness: 11.1 mm
Conditioning: 24 hr. Soak

Panel No.	Sample No.	Dry Thickness Position 1	2	3	4	Wet Thickness Position 1	2	3	4	Average Thick. Swell
		mm	mm	mm	mm	mm	mm	mm	mm	%
2.5-1	1	10.95	10.95	11.05	11.05	11.80	11.90	11.85	11.90	9
	2	10.85	10.80	10.90	10.90	11.90	11.90	11.80	11.90	
2.5-2	1	10.90	10.85	10.70	10.75	12.10	11.85	12.25	11.95	10
	2	10.90	10.75	10.80	10.90	11.75	11.80	11.75	11.80	
2.5-4	1	10.90	10.85	10.90	10.90	12.10	12.00	11.90	12.10	11
	2	10.85	10.80	10.85	10.80	11.90	12.05	12.05	12.40	
No.		6	6	6	6	6	6	6	6	3
Avg.		10.89	10.83	10.87	10.88	11.93	11.92	11.93	12.01	10

ALBERTA RESEARCH COUNCIL

FOREST PRODUCTS LABORATORY

Table F-9

Linear Expansion-Oven Dry to Saturated
(CAN3-0437.1-M85)

Client: ARC
Test Date: March 30, 1987
Proj. Ref.: 303221

Test Material: 2.5 % Iso.
Nom. Thickness: 11.1 mm
Conditioning: OD to Saturated

Panel No.	Sample No.		Oven Dry Gauge Length		Vac.-Pressure Gauge Length		Linear Expansion		Avg. Linear Expansion	
	Par.	Perp.	Par.	Perp.	Par.	Perp.	Par.	Perp.	Par.	Perp.
			mm	mm	mm	mm	%	%	%	%
2.5-1	1	3	235.25	236.35	235.90	237.05	0.28	0.30	0.22	0.25
	2	4	235.75	237.25	236.15	237.75	0.17	0.21		
2.5-2	1	3	236.20	236.15	236.95	236.45	0.32	0.13	0.30	0.14
	2	4	236.05	236.50	236.70	236.85	0.28	0.15		
2.5-4	1	3	235.45	235.60	236.30	236.30	0.36	0.30	0.31	0.33
	2	4	236.05	236.50	236.65	237.35	0.25	0.36		
No.			6	6	6	7	6	6	3	3
Avg.			235.79	236.39	236.44	203.11	0.28	0.24	0.28	0.24

ALBERTA RESEARCH COUNCIL

FOREST PRODUCTS LABORATORY

APPENDIX G

Test Results for Control Panels Having 2.5% Powder PF Resin

Table G-1

SUMMARY TABLE
GRADE PROPERTIES
(CAN3-0437.1-M85)

Client: Alberta Research Council
Test Date: March 10, 1987
Proj.Ref.: 303221

Test Material: Waferboard w/2.5% PF Resin
Nom. Thickness: 11.1 mm
Conditioning: As per test requirements

	Units	CAN3-0437 R-1 Req.	Dir'n	Panel Number PF-1	PF-2	PF-3	PF-4	PF-5	4 Panel Avg.
Modulus of rupture	MPa	17.2	Para	-	29.6	32.7	32.9	35.8	32.8
		17.2	Perp	-	27.1	33.0	35.2	28.3	30.9
Modulus of elasticity	MPa	3100	Para	-	4800	5000	5300	5100	5050
		3100	Perp	-	4200	5400	5200	4900	4930
Internal bond	MPa	0.345		-	0.630	0.593	0.631	0.580	0.608
Bond durability - MOR after 2 h boil	MPa	8.6	Para	-	17.0	17.4	19.0	16.3	17.4
		8.6	Perp	-	17.7	19.3	15.9	20.1	18.3
Thickness swell - 24 h soak - 12.7 mm or thinner	%	25		-	17	15	16	17	16
Linear expansion - oven dry to saturated	%	0.40	Para	-	0.19	0.23	0.28	0.35	0.26
		0.40	Perp	-	0.26	0.25	0.19	0.25	0.24
General									
Moisture Content	%	8 max.		-	3	3	3	4	4
Density	kg/cu.m	None		-	656	705	645	629	659

ALBERTA RESEARCH COUNCIL
FOREST PRODUCTS LABORATORY

Table G-2

Moisture Content and Density
(CAN3-0437.1-M85)

Client: ARC
Test Date: March 26,1987
Proj. Ref.: 303221

Test Material: 2.5% Phenolic
Nom. Thickness: 11.1 mm
Conditioning: Oven Dry& at Test

Panel No.	Sample No.	Length	Width	Thick-ness	TEST Weight	O.D. Weight	M.C.	Avg. M.C.	Density at Test	Avg. Density at Test
		mm	mm	mm	g	g	%	%	kg/cu.m	kg/cu.m
	1	75.0	74.5	10.65	37.4	36.3	3		628	
PF-2	2	75.0	75.0	10.70	41.1	40.3	2	3	683	656
	1	75.5	75.5	10.60	42.9	41.4	4		710	
PF-3	2	75.0	75.5	10.75	42.6	41.9	2	3	700	705
	1	74.5	74.5	10.70	34.5	33.2	4		581	
PF-4	2	75.5	75.5	10.70	43.3	42.6	2	3	710	645
	1	75.5	75.5	10.75	39.9	38.5	4		651	
PF-5	2	75.5	75.5	10.80	37.4	36.3	3	4	608	629
No.		8	8	8	8	8	8	4	8	4
Avg.		75.2	75.2	10.71	39.9	38.8	3	3	659	659

ALBERTA RESEARCH COUNCIL

FOREST PRODUCTS LABORATORY

Table G-3

MOR & MOE DRY-Parallel
(CAN3-0437.1-M85)

Client: ARC
Test Date: March 25,1987
Proj.Ref.: 303221
Test Material: 2.5% Phenolic
Nom. Thickness: 11.1 mm
Conditioning: As Received
Span: 266.0 mm

Panel No.	Sample No.	Thick-ness	Width	Max. Load	MOE	Avg. MOE	MOR	Avg. MOR
		mm	mm	N	MPa	MPa	MPa	MPa
	1	10.70	75.0	718	5700		33.4	
PF-2	2	10.62	75.0	571	4500	4800	26.9	29.6
	3	10.72	75.0	618	4300		28.6	
	1	10.72	75.2	836	5500		38.6	
PF-3	2	10.54	75.2	712	4800	5000	34.0	32.7
	3	10.58	75.2	536	4700		25.4	
	1	10.88	74.4	824	6200		37.3	
PF-4	2	10.74	74.4	814	5300	5300	37.8	32.9
	3	10.72	74.6	506	4300		23.6	
	1	11.08	75.4	906	5900		39.1	
PF-5	2	10.82	75.2	700	4800	5100	31.7	35.8
	3	10.84	75.4	814	4700		36.7	
No.		12	12	12	12	4	12	4
Avg.		10.75	75.0	713	5050	5050	32.8	32.8

ALBERTA RESEARCH COUNCIL

FOREST PRODUCTS LABORATORY

Table G-4

MOR & MOE DRY-Perpendicular
(CAN3-0437.1-M85)

Client:	ARC	Test Material:	2.5% Phenolic
Test Date:	March 25,1987	Nom. Thickness:	11.1 mm
Proj.Ref.:	303221	Conditioning:	As Received
		Span:	266.0 mm

Panel No.	Sample No.	Thick-ness	Width	Max. Load	MOE	Avg. MOE	MOR	Avg. MOR
		mm	mm	N	MPa	MPa	MPa	MPa
	4	10.66	75.2	588	4100		27.5	
PF-2	5	10.64	75.0	543	3800	4200	25.5	27.1
	6	10.52	75.0	591	4600		28.4	
	4	10.58	75.0	656	5200		31.2	
PF-3	5	10.72	75.2	717	5700	5400	33.1	33.0
	6	10.60	75.2	737	5200		34.8	
	4	10.60	75.4	674	4900		31.7	
PF-4	5	10.58	75.2	655	4600	5200	31.0	35.2
	6	10.80	75.4	946	6200		42.9	
	4	10.78	75.4	512	5000		23.3	
PF-5	5	10.80	75.4	596	4700	4900	27.0	28.3
	6	10.88	75.2	768	5000		34.4	
No.		12	12	12	12	4	12	4
Avg.		10.68	75.2	665	4930	4930	30.9	30.9

ALBERTA RESEARCH COUNCIL

FOREST PRODUCTS LABORATORY

Table G-5

Internal Bond
(CAN3-0437.1-M85)

Client: ARC
Test Date: March 26,1987
Proj.Ref.: 303221

Test Material: 2.5% Phenolic
Nom. Thicknes: 11.1 mm
Conditioning: As Received

Panel No.	Sample Number	Sample Length	Sample Width	Maximum Load	Internal Bond Strength	Average For Panel
		mm	mm	N	MPa	MPa
	1	49.8	50.2	1766	0.706	
	2	50.2	50.2	1181	0.469	
PF-2	3	49.8	50.2	1623	0.649	0.630
	4	49.8	49.4	1608	0.654	
	5	49.8	49.8	1754	0.707	
	6	49.8	50.4	1489	0.593	
	1	50.4	49.6	1707	0.683	
	2	50.2	49.8	1271	0.508	
PF-3	3	50.4	49.8	1478	0.589	0.593
	4	50.0	50.2	1364	0.543	
	5	50.2	49.8	1415	0.566	
	6	50.4	49.4	1657	0.666	
	1	50.0	49.6	1399	0.564	
	2	49.2	49.8	1558	0.636	
PF-4	3	50.0	49.4	1755	0.711	0.631
	4	49.8	49.6	1546	0.626	
	5	50.2	49.6	1598	0.642	
	6	49.6	50.0	1504	0.606	
	1	49.6	50.2	1619	0.650	
	2	49.6	50.2	1444	0.580	
PF-5	3	49.8	50.4	1548	0.617	0.580
	4	49.6	50.4	1458	0.583	
	5	49.4	50.2	1323	0.533	
	6	49.6	50.2	1283	0.515	
No.		24	24	24	24	4
Avg.		49.9	49.9	1510	0.608	0.608

ALBERTA RESEARCH COUNCIL

FOREST PRODUCTS LABORATORY

Table G-6

Bond Durability-MOR after 2 Hour Boil-Parallel
(CAN3-0437.1-M85)

Client: ARC
Test Date: March 25,1987
Proj.Ref.: 303221
Span: 266 mm

Test Material: 2.5% Phenolic
Nom. Thickness: 11.1 mm
Conditioning: 2 Hour Boil

Panel No.	Sample No.	Sample Thickness	Sample Width	Maximum Load	MOR	Average MOR for Panel
		mm	mm	N	MPa	MPa
	1	10.58	75.0	344	16.3	
PF-2	2	10.64	75.2	410	19.2	17.0
	3	10.72	75.2	333	15.4	
	1	10.58	75.2	330	15.6	
PF-3	2	10.48	75.2	356	17.2	17.4
	3	10.64	75.2	411	19.3	
	1	10.70	74.6	398	18.6	
PF-4	2	10.76	74.6	462	21.3	19.0
	3	10.88	74.6	377	17.0	
	1	10.84	75.2	414	18.7	
PF-5	2	10.90	75.2	346	15.5	16.3
	3	10.88	75.2	326	14.6	
No.		12	12	12	12	4
Avg.		10.7	75.0	376	17.4	17.4

ALBERTA RESEARCH COUNCIL

FOREST PRODUCTS LABORATORY

Table G-7

Bond Durability-MOR after 2 Hour Boil-Perpendicular
(CAN3-0437.1-M85)

Client: ARC
Test Date: March 25,1987
Proj.Ref.: 303221
Span: 266 mm

Test Material: 2.5% Phenolic
Nom. Thickness: 11.1 mm
Conditioning: 2 Hour Boil

Panel No.	Sample No.	Sample Thickness	Sample Width	Maximum Load	MOR	Average MOR for Panel
		mm	mm	N	MPa	MPa
	4	10.78	75.2	440	20.1	
PF-2	5	10.70	75.0	366	17.0	17.7
	6	10.72	75.2	348	16.1	
	4	10.78	75.0	343	15.7	
PF-3	5	10.62	75.2	395	18.6	19.3
	6	10.66	75.2	503	23.5	
	4	10.82	75.4	365	16.5	
PF-4	5	10.56	75.4	305	14.5	15.9
	6	10.66	75.2	361	16.9	
	4	10.78	75.4	389	17.7	
PF-5	5	10.80	75.4	485	22.0	20.1
	6	10.86	75.4	462	20.7	
No.		12	12	12	12	4
Avg.		10.73	75.3	397	18.3	18.3

ALBERTA RESEARCH COUNCIL

FOREST PRODUCTS LABORATORY

Table G-8
Thickness Swell
(CAN3-0437.1-M85)

Client: ARC
Test Date: March 23,1987
Proj. Ref.: 303221

Test Material: 2.5% Phenolic
Nom. Thickness: 11.1 mm
Conditioning: 24 hr. Soak

Panel No.	Sample No.	Dry Thickness Position 1	2	3	4	Wet Thickness Position 1	2	3	4	Average Thick. Swell
		mm	mm	mm	mm	mm	mm	mm	mm	%
PF-2	1	10.55	10.55	10.40	10.60	11.85	12.15	12.10	12.20	17
	2	10.45	10.50	10.50	10.55	12.90	12.10	12.30	12.45	
PF-3	1	10.65	10.60	10.55	10.55	12.45	12.20	12.25	12.25	15
	2	10.60	10.50	10.65	10.65	12.05	12.10	12.05	11.95	
PF-4	1	10.60	10.65	10.55	10.60	12.60	12.30	12.25	12.10	16
	2	10.60	10.65	10.65	10.60	12.15	12.45	12.40	11.95	
PF-5	1	10.95	10.90	10.85	10.90	12.45	12.90	12.80	12.45	17
	2	10.80	10.75	10.85	10.85	12.35	12.85	13.05	12.50	
No.		8	8	8	8	8	8	8	8	4
Avg.		10.65	10.64	10.63	10.66	12.35	12.38	12.40	12.23	16

ALBERTA RESEARCH COUNCIL

FOREST PRODUCTS LABORATORY

Table G-9

Linear Expansion-Oven Dry to Saturated
(CAN3-0437.1-M85)

Client: ARC
Test Date: March 30/87
Proj. Ref.: 303221

Test Material: 2.5 % PF
Nom. Thickness: 11.1 mm
Conditioning: OD to Saturated

Panel No.	Sample No.		Oven Dry Gauge Length		Vac.-Pressure Gauge Length		Linear Expansion		Avg. Linear Expansion	
	Par.	Perp.	Par.	Perp.	Par.	Perp.	Par.	Perp.	Par.	Perp.
			mm	mm	mm	mm	%	%	%	%
PF-2	1	3	235.80	235.60	236.20	236.20	0.17	0.25	0.19	0.26
	2	4	236.70	236.40	237.20	237.05	0.21	0.27		
PF-3	1	3	236.10	236.10	236.70	236.45	0.25	0.15	0.23	0.25
	2	4	236.55	235.25	237.05	236.10	0.21	0.36		
PF-4	1	3	236.20	235.90	236.85	236.25	0.28	0.15	0.28	0.19
	2	4	236.20	236.50	236.85	237.05	0.28	0.23		
PF-5	1	3	236.70	235.30	237.60	235.95	0.38	0.28	0.35	0.25
	2	4	236.10	236.30	236.85	236.85	0.32	0.23		
No.			8	8	8	8	8	8	4	4
Avg.			236.29	235.92	236.91	236.49	0.26	0.24	0.26	0.24

ALBERTA RESEARCH COUNCIL

FOREST PRODUCTS LABORATORY