CHAPTER IV

RESULTS AND DISCUSSION

The effect of various parameters on processing conditions and mechanical properties of rubber wooden particleboard were studied. In this work, the flakes were weighed and placed in a rotary drum blender and the required amount of resin was applied to the flakes with air-atomization nozzles. The blended flakes were matted by hand on stainless cauls with a forming box. Then, the completely formed mats were prepressed to consolidate the mat, transferred to a single-opening hot press, and pressed with the specified conditions. The required density was 750 kg/m^3. After pressing, they were allowed to cool, trimmed and conditioned before cutting to the test specimens. The rubber wooden particleboards were tested under both normal and vigorous conditions. The microstructures of fracture surface were observed by means of a scanning electron microscope. The physical properties of particleboard were investigated. The efficiency of binders was studied by the staining technique.

4.1 Characteristic of Rubber Wood Flake.

In this study, rubber wood flakes were divided into two groups: the coarse flakes for the core layer and the fine flakes for both surface layers. The bulk density of coarse flake was 250 kg/m^3, and the fine one was 350 kg/m^3. The pHs of the coarse and fine flakes were 5.83 and 6.74, respectively. The size distribution of both particles plays a significant role on the properties of the finished products. The particle size distribution of both rubber wood flakes and the slenderness ratio are presented in Tables 4.1-4.2. About three fourths (74.64%) and two thirds (63.71%) of the total weight of each wood flakes were composed of medium coarse and medium fine flakes, respectively.

Table 4.1 Size distribution of coarse rubber wood flakes.

Mesh size (mesh)	Weight fraction (%)	Cumulative weight fraction (%)	Slenderness ratio
+5	10.47	10.47	22.04
+12	41.01	51.48	17.59
+20	33.63	85.11	13.30
+40	11.71	96.82	14.66
+60	1.89	98.71	17.78
-60	1.29	100.00	---

Table 4.2 Size distribution of fine rubber wood flakes.

Mesh size (mesh)	Weight fraction (%)	Cumulative weight fraction (%)	Slenderness ratio
+20	5.440	5.40	9.13
+40	36.88	42.28	10.03
+60	26.29	68.57	12.43
+80	15.05	83.62	---
+100	6.90	90.52	---
-100	9.48	100.00	---

4.2 Investigation of Suitable Releasing Agents

Under heat and pressure, pMDI had a tendency to adhere to the plates (cauls) which caused a serious problem in a fabrication step. The suitable releasing agent must be investigated. In this study, silicone released mold, paraffin oil, teflon coated tape, aluminium foil and polyol were selected. In this work, the mats were prepared from flakes which were sprayed with 6% pMDI for both core and surface layers, and the stainless plates treated with those releasing agents were used in mat forming. The flakes were compressed to finish boards. The cure time of 5 min. and cure temperature of 160 ^{0}C were used. After pressing, the mats were removed from the plates. The ease of removing and the quality of surface of final product were observed. The effects of releasing agent on surface quality are shown in Table 4.3.

From Table 4.3, the particleboard prepared by using the teflon tape as releasing agent gave the good quality surface which was slightly rough. This was a result of the elasticity of the tape. The board was easily removed. Polyol releasing agent also gave the good quality surface which was very smooth. The board was easily removed from the plates because the contact area was modified by polyurethane which did not adhere the plates. Therefore, polyol and taflon tape were the suitable releasing agents.

Table 4.3 Effect of releasing agents on surface quality of the particleboard.

Releasing agent	Ease of removing	Quality of the surface
Paraffin oil	difficult	poor (rough surface)
Teflon tape	very easy	good (slightly rough surface)
Foil sheet	rather difficult	very good (smooth surface)
Polyol	easy	very good (smooth surface)
Silicone released mold	difficult	poor (rough surface)

4.3 Effect of Releasing Agent

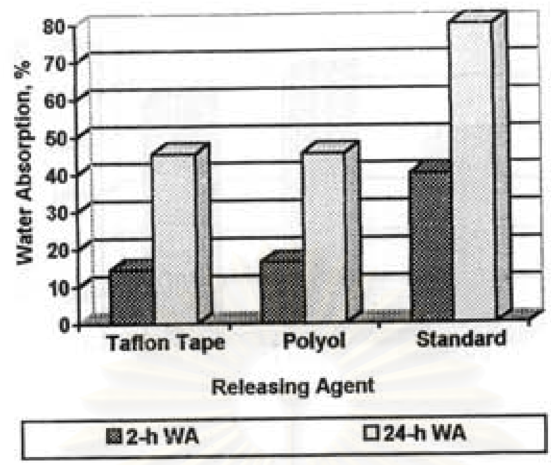
The effect of releasing agents on the mechanical properties is summarized in Table 4.4. Particleboards using teflon tape as releasing agent exhibited significantly better properties than those with polyol. Water absorption and thickness swelling were lower than the standard values (Figures 4.1a-4.1b). The internal bond strength both dry and wet conditions were higher than the standard values (Figure 4.1e). The lower water absorption and thickness swelling properties of particleboard using teflon tape as releasing agent may be explained in the polyurea structure is more hydrophobic than the polyurethane surfaces using polyol as a releasing agent. However, the modulus of rupture and modulus of elasticity (Figures 4.1c-4.1d) of particleboards using polyol as the releasing agent were higher because polyurethane is more elastic.

Considering the properties of particleboard, the cost of a releasing agent, and the ease of application, the teflon releasing agent gave the product with better properties and excellent ease of removing but the teflon releasing tape is very expensive. Polyol releasing agent gave the product with slightly lower properties. The properties of particleboard using polyol and teflon tape as releasing agents were higher than the corresponding standard value of medium-density particleboard evaluated by the TIS 867-2533. The teflon releasing tape gave the particleboard with slightly better properties than did the polyol (insignificant difference). Therefore, polyol was justified to be used as releasing agent for the following experiments.

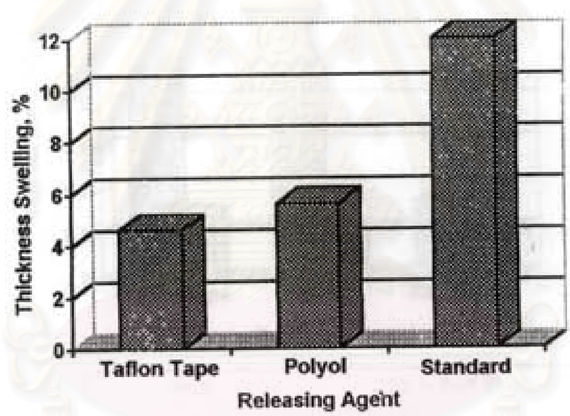
Table 4.4 Properties of particleboard prepared with various releasing agents.

Properties	Releasing agents	
	Teflon tape	Polyol
Moisture content (MC), %	4.91 (0.23)	4.90 (0.19)
2-h water absorption (WA), %	14.32 (1.94)	16.41 (3.78)
24-h water absorption (WA), %	45.46 (4.36)	45.45 (7.57)
Thickness swelling (TS), %	4.61 (0.22)	5.63 (0.80)
Modulus of rupture (MOR), MPa	16.79 (2.10)	19.63 (1.29)
Modulus of elasticity (MOE), MPa	2417.29 (281)	2678.49 (144)
Internal bond (IB), MPa	1.35 (0.16)	1.15 (0.20)
2-h boiled internal bond (IB), MPa	0.29 (0.06)	0.19 (0.09)
2-h boiled modulus of rupture (MOR), MPa	8.22 (4.17)	---

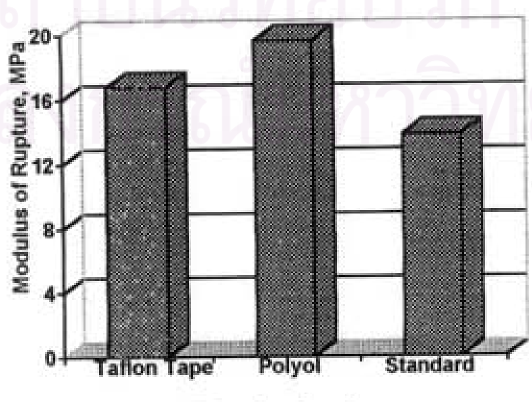
Values in parentheses are standard deviations.


Water Absorption, %
80
70
60
50
40
30
20
10
0
Taflon Tape
Polyol
Standard
Releasing Agent
2-h WA
24-h WA

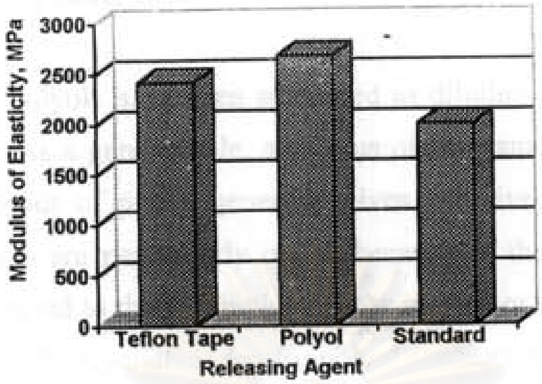
(a)


Thickness Swelling, %
12
10
8
6
4
2
0
Taflon Tape
Polyol
Standard
Releasing Agent

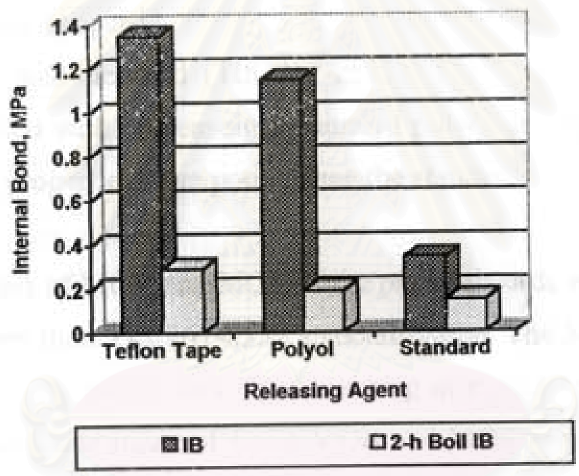
(b)


Modulus of Rupture, MPa
20
16
12
8
4
0
Taflon Tape
Polyol
Standard
Releasing Agent

(c)



(d)



(e)

Figure 4.1 Effect of releasing agents on the properties of particleboard.

4.4 Effect of Isocyanate Index

Several polyols have been suggested as diluting agents in order to reduce the costs of pMDI. As a general rule, a surplus of isocyanate leads to a harder adhesive film, and a surplus of polyol generally gives adhesive films with higher elasticity. Polyether polyols are particularly useful because of their lower viscosity. They are therefore well-suited to the production of low solvent or solvent free reaction adhesive [21]. The effect of isocyanate index (or polyol content) on the mechanical properties is shown in Table 4.5.

For particleboards with isocyanate index of 1-3, the water absorption and thickness swelling properties (Figures 4.2a-4.2b) were poorer than the corresponding medium-density particleboard (TIS 867-2532). The water absorption and thickness swelling decreased with decreasing amount of polyol or increasing isocyanate index. However, these properties were poorer than the standard.

The values of MOR and MOE of the particleboards with isocyanate index of 1 and 2 were lower than TIS 867-2532 standard value. The MOR and MOE increased with increasing isocyanate index (or decreasing of polyol content). Figures 4.2c-4.2d show that at isocyanate index of 3, the MOR and MOE were higher than the standard values. Moreover, the moisture content of the particleboards with polyol was higher than that without polyol. The internal bond (dry) properties of particleboard with isocyanate index of 2 and 3 were better than standard (Figure 4.2e). The dry internal bond strength increased significantly with increasing isocyanate index. But in wet condition, the internal bond strength (2-h boiled IB) was lower than the standard value as shown in Figure 4.2e and Table 4.5.

Usually, the pMDI binder is processed without catalysts or other additives. Therefore, the need to prepare binder mixtures and the generation of liquid waste is eliminated. The storage stability of the chips treated with the binders at room temperature is approximately 5 hours [21]. From this experiment, the values of water absorption, thickness swelling of particleboard with polyol were higher than the standard value and the values of MOR and MOE were lower than the standard value. Therefore, pMDI without polyol was used for the following experiment.

Table 4.5 Properties of particleboard prepared at various isocyanate indexes.

Properties	Isocyanate index			
	1	2	3	∞
MC, %	9.85 (0.19)	8.82 (0.19)	8.80 (0.22)	4.90 (0.19)
2-h WA, %	101.98 (5.80)	80.77 (3.30)	74.69 (4.98)	16.41 (3.78)
24-h WA, %	117.60 (8.20)	93.32(3.37)	85.02 (5.22)	45.45 (7.57)
TS, %	62.05 (8.75)	39.51 (2.61)	30.86 (2.08)	5.63 (0.80)
MOR, MPa	8.09 (1.00)	13.21 (1.87)	16.03 (1.16)	19.63 (1.29)
MOE, MPa	1308.74 (210)	1991.70 (208)	2253.86 (197)	2678.49 (144)
IB, MPa	0.31 (0.12)	0.52 (0.16)	0.77 (0.12)	1.15 (0.20)
2-h boiled IB, MPa	-	-	-	0.19 (0.09)
2-h boiled MOR, MPa	-	3.14 (1.51)	4.83 (2.22)	-

∞ = pMDI

Values in parentheses are standard deviations.

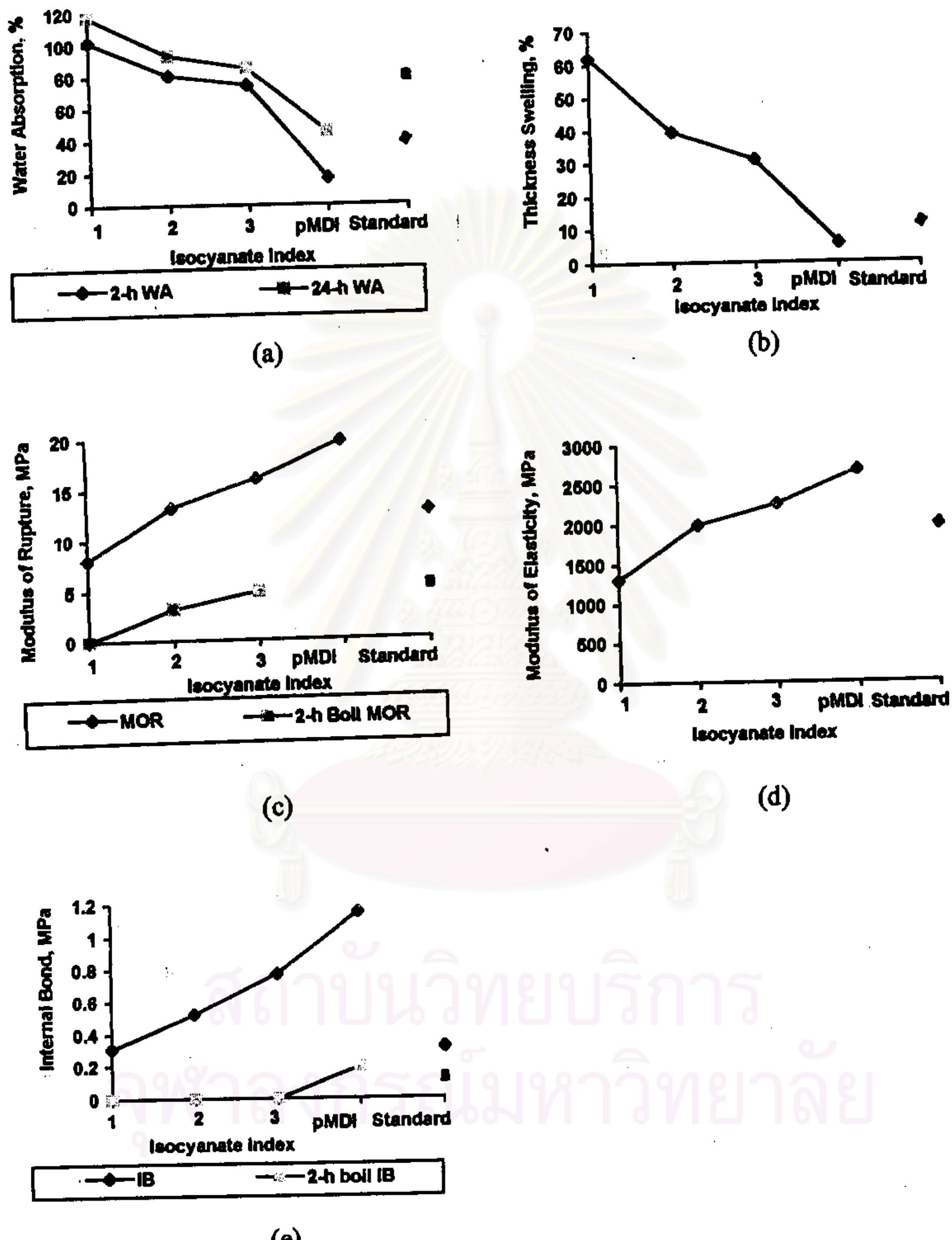


Figure 4.2 Effect of isocyanate index on the properties of particleboard.

4.5 Effect of pMDI Content in Surface/Core Layers

In this work, cure time of 5 min. and cure temperature of 160 ^{0}C were used. The effect of pMDI on the mechanical properties of particleboard with pMDI binder is shown in Table 4.6. From Figure 4.3a, the water absorption values decreased with increasing the pMDI content in the core layer (7% in surface and 3-5% in core). The particleboard with 6/6 and 7/5 pMDI content gave the lowest water absorption value which was about half of the standard value.

The thickness swelling decreased with increasing the pMDI content in the core layer as shown in Figure 4.3b. The thickness swelling values of particleboard with pMDI contents of 6/6, 7/5 and 7/4 were 5.63%, 5.60% and 5.77%, respectively, which was about half of the standard value.

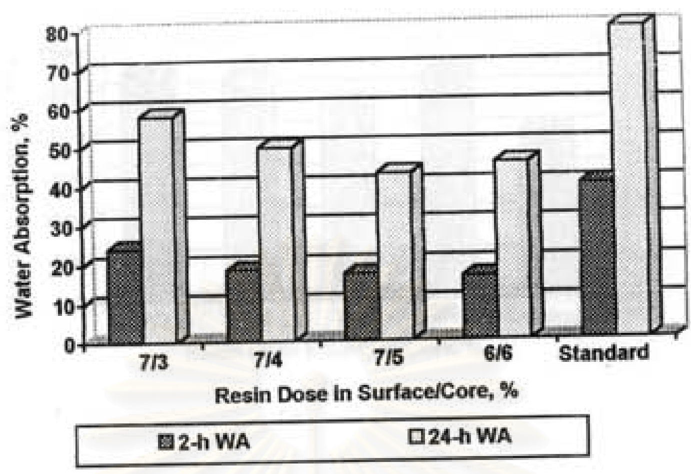
Figures 4.3c-4.3d show the effect of pMDI content in the core and surface on the MOR and MOE properties at dry and wet condition. At pMDI content of 7% in surface layers, the MOR values both in dry and wet condition and MOE values were almost not changed with increasing pMDI content in the core layer. Figure 4.3e shows the internal bond strength values at both dry and wet conditions. At pMDI content of 7% in surface layer, the internal bond strength values at both dry and wet conditions increased with increasing of pMDI content in the core layer. At dry test condition, the internal bond strength values were about 3 times the standard value of TIS 867-2533.

The quality of particleboard surfaces was improved by the increasing pMDI content in the surface layers from 6% to 7%. According to TIS 867-2532 (the standard for interior particleboard), all properties of particleboard with pMDI content of 7/3 were above the standard. Therefore, this particleboard could be used as good quality panels for interior application. For exterior applications, the particleboard with pMDI content at the surface layer of 7% and the core of 5% gave the superior properties. Therefore, particleboard with pMDI content of 7/5 was selected for the following experiments.

Table 4.6 Properties of particleboard prepared with various pMDI contents in surface/core layers.

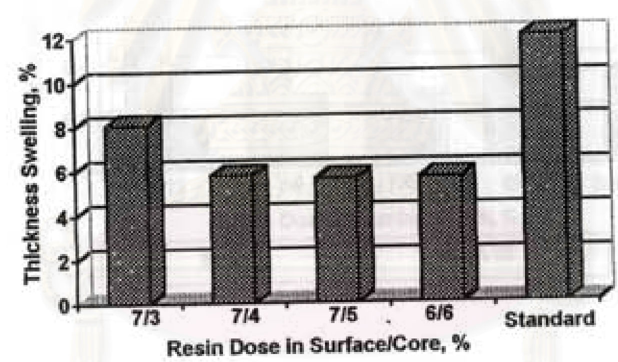
Properties	pMDI dose in surface/core, %			
	7/3	7/4	7/5	6/6
MC, %	5.64 (0.26)	4.88 (1.10)	5.49 (0.27)	4.90 (0.19)
2-h WA, %	24.19 (5.28)	18.50 (5.66)	17.32 (4.04)	16.41 (3.78)
24-h WA, %	58.00 (10.21)	49.66 (15.79)	42.88 (5.28)	45.45 (7.57)
TS, %	8.07 (1.52)	5.77 (0.76)	5.60 (1.24)	5.63 (0.80)
MOR, MPa	19.63 (1.80)	19.30 (1.88)	18.00 (2.00)	19.63 (1.29)
MOE, MPa	2721.46 (223)	2642.64 (328)	2334.52 (239)	2678.49 (144)
IB, MPa	1.00 (0.19)	1.07 (0.21)	1.07 (0.19)	1.15 (0.20)
2-h boiled IB, MPa	0.16 (0.03)	0.25 (0.04)	0.26 (0.07)	0.19 (0.09)
2-h boiled MOR, MPa	7.55 (3.79)	7.46 (3.37)	7.32 (3.47)	-

Values in parentheses are standard deviations.



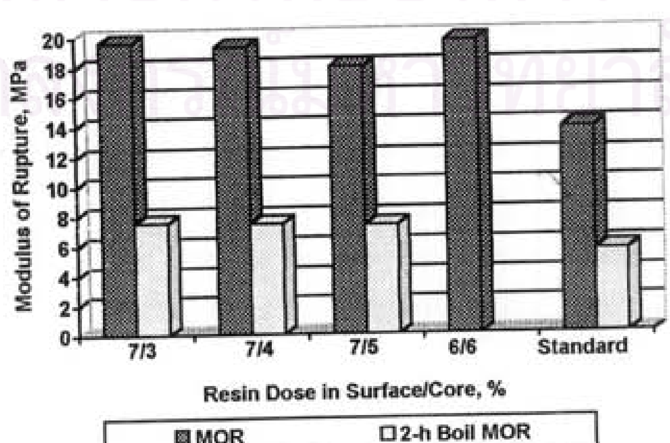
Water Absorption, %
80
70
60
50
40
30
20
10
0
7/3
7/4
7/5
6/6
Standard
Resin Dose in Surface/Core, %
2-h WA
24-h WA

(a)



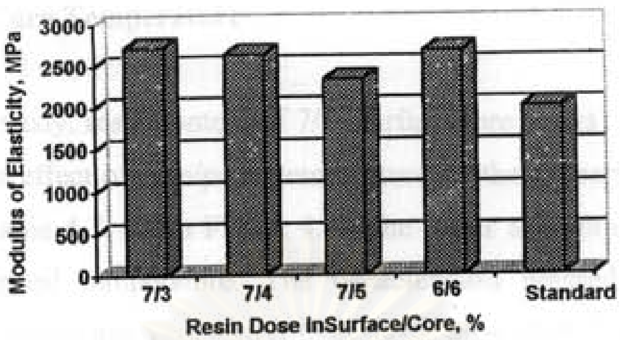
Thickness Swelling, %
12
10
8
6
4
2
0
7/3
7/4
7/5
6/6
Standard
Resin Dose in Surface/Core, %

(b)

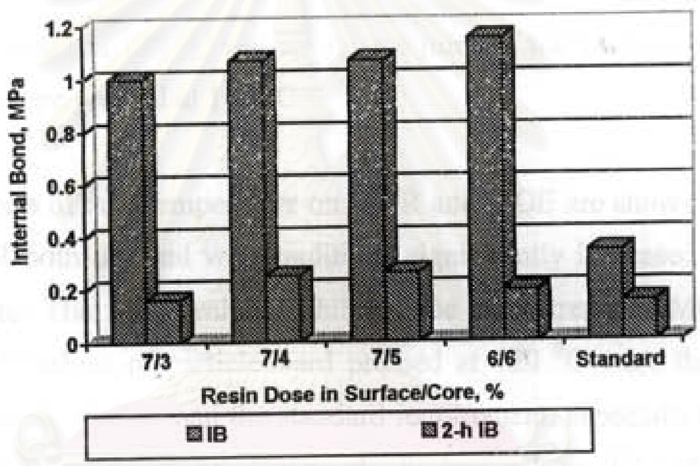


Modulus of Rupture, MPa
20
18
16
14
12
10
8
6
4
2
0
7/3
7/4
7/5
6/6
Standard
Resin Dose in Surface/Core, %
MOR
2-h Boil MOR

(c)



(d)



(e)

Figure 4.3 Effect of resin dose in surface/core on the properties of particleboards.

4.6 Effect of Cure Temperature

In this study, resin content of 7/5 (surface/core layers) and cure time of 5 min. were used. The effect of cure/press temperature on the properties of the particleboard is shown in Table 4.7. From Figure 4.4a, the water absorption values increase with increasing pressed temperature. The particleboard pressed at 120 ^{0}C exhibited significantly lower water absorption than those pressed at 140 ^{0}C and 160 ^{0}C. Also after 24-h soaking, the particleboard pressed at 120 ^{0}C exhibited the lowest water absorption. The thickness swelling properties (Figure 4.4b) of the particleboard increased with increasing cure temperature. The thickness swelling values of particleboard pressed at 120 ^{0}C was about one third of the standard requirement and about half of the one pressed at 160 ^{0}C.

The effects of cure temperature on MOR and MOE are shown in Figures 4.4c-4.4d. The MOR both dry and wet conditions significantly increased with increasing cure temperature. The MOE values exhibited the same trend as MOR values. The MOR and MOE values of particleboard pressed at 120 ^{0}C were the lowest. These values were slightly greater than the standard requirement, especially the MOE value. The particleboard pressed at 160 ^{0}C gave the highest values of MOR and MOE both dry and wet conditions. The internal bond strength values of the samples in dry condition was not significantly different (Figure 4.4e). The particleboard pressed at 120 ^{0}C showed the lowest value which was still higher than the standard value of about 2 times. For internal bond strength after 2-h boiled, the values were clearly different, the internal bond strength increased with increasing cure temperature.

High cure temperature, from about 180 to 200 ^{0}C is needed for particleboard using the conventional binder (phenol-formaldehyde). The cure rate of the amino group is increased by high temperatures, but lower pressed temperature can be used rather successfully. However, the new process is usually designed to be operated at much high temperatures, in particular, in the single-opening type where the press time is extremely important. Heat from the press is also supplemented from the heat developed by the condensation reaction of the resin cure [20]. For pMDI resin, it showed that particleboard used pMDI could be cured at lower temperatures than that of conventional binders. In the work of Wendler, S. L., and Frazier, C. E., [40] they reported that at low moisture content, low cure temperatures promoted urea and biuret formation. High cure temperatures also produced urea and biuret, but biuret appeared to be dominant. In the study of Tabarsa, T., and Chui, Y.H. [52], they reported that an increase in pressed temperature resulting to a decrease in equilibrium moisture content.

Although the minimum values of 2-h and 24-h water absorption and thickness swelling were achieved at cure temperature of 120 ^{0}C. But the maximum values of MOR both in dry and wet conditions, MOE and internal bond strength were achieved at cure temperature of 160 ^{0}C. Therefore, cure temperature of 160 ^{0}C was selected for the following experiments.

Table 4.7 Properties of particleboard prepared at various cure temperatures.

Properties	Cure temperature, ^{0}C		
	120	140	160
MC, %	8.45 (0.34)	8.13 (0.22)	5.49 (0.27)
2-h WA, %	14.24 (0.95)	16.92 (2.43)	17.32 (4.04)
24-h WA, %	40.95 (2.76)	46.14 (4.86)	42.88 (5.28)
TS, %	3.92 (0.30)	4.36 (0.16)	5.60 (1.24)
MOR, MPa	14.45 (1.17)	16.50 (1.12)	18.00 (2.00)
MOE, MPa	2020.07 (263)	2251.41 (118)	2334.52 (239)
IB, MPa	0.91 (0.13)	1.18 (0.13)	1.07 (0.19)
2-h boiled IB, MPa	0.21 (0.03)	0.23 (0.06)	0.26 (0.07)
2-h boiled MOR, MPa	6.17 (2.81)	6.77 (3.04)	7.32 (3.47)

Values in parentheses are standard deviations.

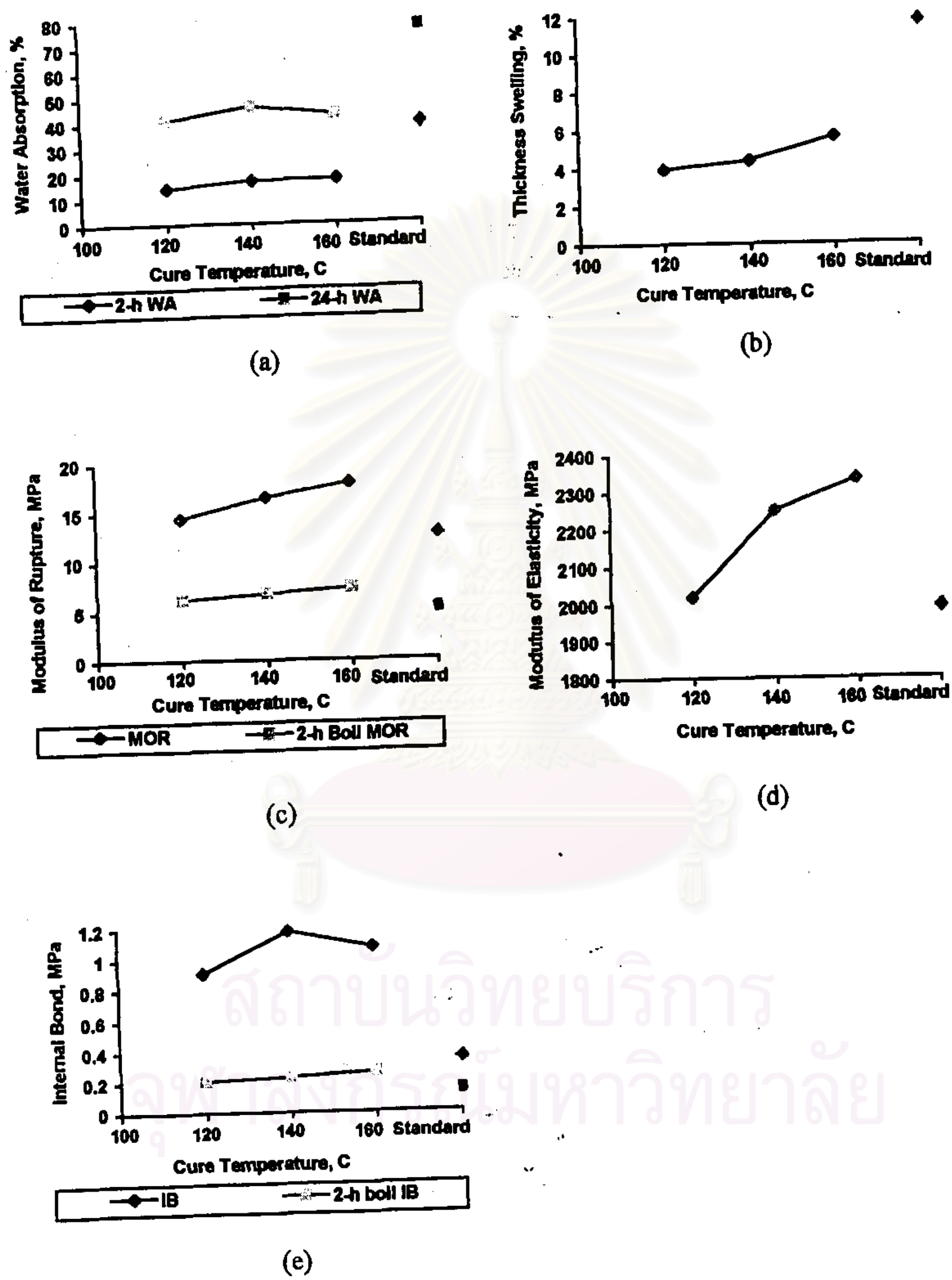


Figure 4.4 Effect of cure temperature on the properties of particleboard.

4.7 Effect of Cure Time

Cure time is one of the major factors which must be considered. In this study, resin dose of 7/5 and cure temperature of 160 ^{0}C were used. The effect of cure time on the properties of the particleboard is shown in Table 4.8. From the Figure 4.5a, the highest values of 2-h and 24-h water absorption were achieved at cure time of 4 min. However, the highest value of water absorption was still lower than the standard value. The highest value of thickness swelling was also achieved at cure time of 4 min. (Figure 4.5b). The optimum cure time which gave the minimum thickness swelling was 5 min. The MOR and MOE properties for both dry and wet conditions (Figures 4.5c-4.5d) of the particleboard for 3, 4 and 5 min. cure time are almost the same, especially the dry MOR. However, the particleboard with cure time of 5 min. had the best properties.

The effect of cure time on internal bond strength for both dry and wet conditions is shown in Figure 4.5e. The highest value of internal bond strength at the dry condition was achieved at the cure time of 3 min., this value was higher than the established standard value about 6 times. At the wet condition, the internal bond strength was not significantly different, However, the internal bond strength values for the wet condition were higher than the standard value about 2 times.

For the pMDI as binder, the good quality of the particleboard can be achieved at low curing time of 3 min. All properties were above the standard of TIS 867-2532. In the study of Wendler, S. L., and Frazier, C. E.,[40] they reported that when pMDI was cured at 120 ^{0}C and with 4.5% wood moisture, the network chemistry did not change significantly with time. From this work, at low cure time of 3 min., the particleboard with good properties was obtained. It indicated that pMDI was a fast cure rate resin. Therefore, for the following experiment for the study of the effect of moisture content, the cure time of 5 min was selected.

Table 4.8 Properties of particleboard prepared at various cure times.

Properties	Cure time, min.		
	3	4	5
MC, %	5.73 (0.24)	5.47 (0.26)	5.49 (0.27)
2-h WA, %	18.15 (2.81)	20.59 (1.42)	17.32 (4.04)
24-h WA, %	40.60 (4.97)	44.89 (3.96)	42.88 (5.28)
TS, %	6.30 (0.34)	6.53 (0.49)	5.60 (1.24)
MOR, MPa	18.05 (2.52)	18.38 (1.96)	18.00 (2.00)
MOE, MPa	2242.36 (302)	2251.80 (224)	2334.52 (239)
IB, MPa	1.94 (0.16)	1.56 (0.15)	1.07 (0.19)
2-h boiled IB, MPa	0.28 (0.03)	0.29 (0.04)	0.26 (0.07)
2-h boiled MOR, MPa	8.01 (3.61)	7.22 (3.28)	7.32 (3.47)

Values in parentheses are standard deviations.

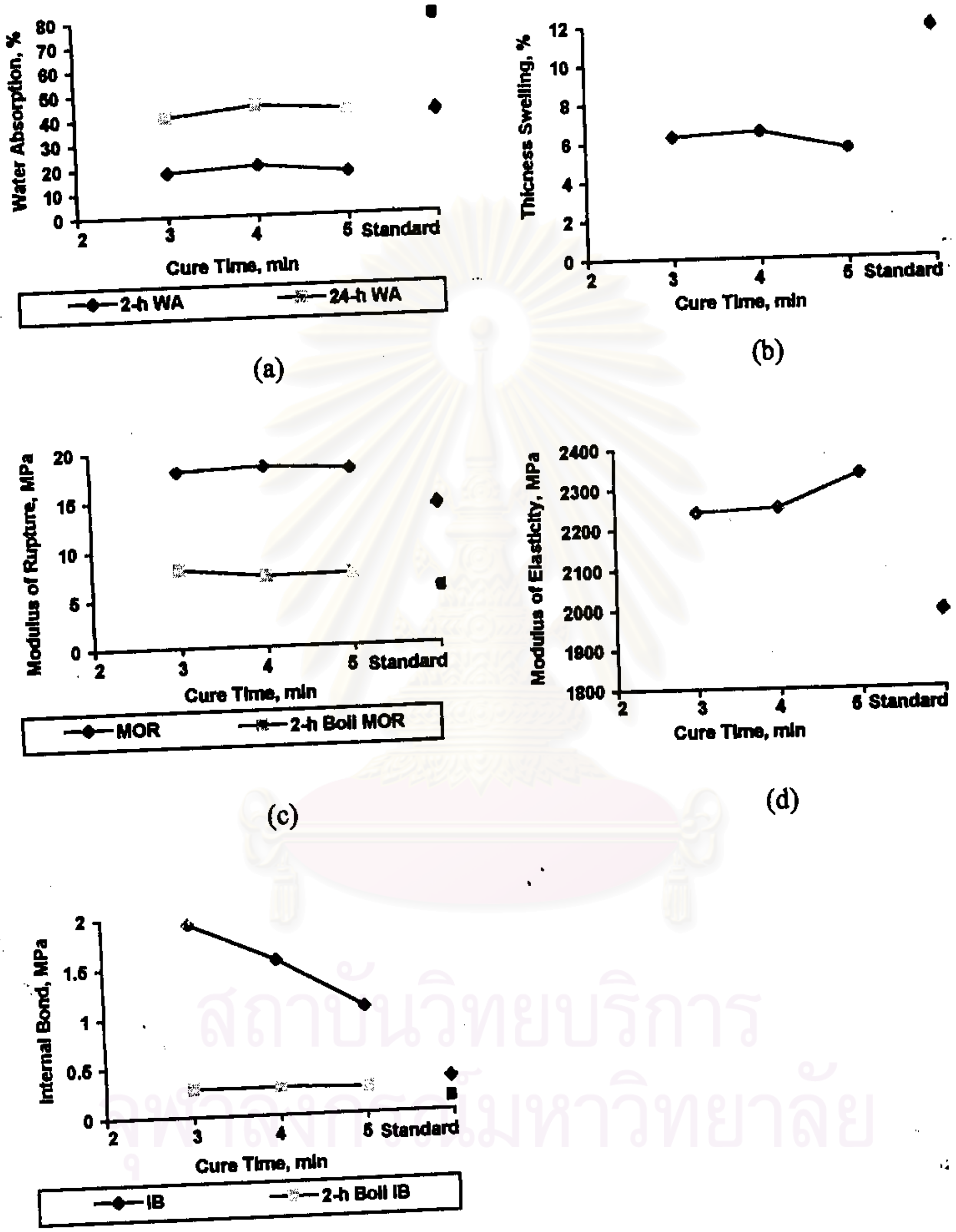


Figure 4.5 Effect of cure time on the properties of particleboard.

4.8 Effect of Moisture Content of the Flake

In this part of the work, pMDI content of 7/5 (surface/core layers), cure time of 5 min. and cure temperature of 160 ^{0}C were used. The effect of moisture content on the mechanical properties of particleboard is presented in Table 4.9. In Figure 4.6a, it was found that lowest value of water absorption of both 2-h and 24-h water soaking were achieved at a moisture content of rubber wood flake of 17%. At this moisture content, the 2-h and 24-h water absorption values were 11.21% and 31.06%, respectively, which were about one fourth and one third times of their standard values. The water absorption values decreased with increasing moisture content of the flakes in the range of 2 to 17%. From Figure 4.6b, the thickness swelling decreased with increasing moisture content of the rubber wood flake. In this work, the lowest value of the thickness swelling was 3.52% at a flake moisture content of 22%, the standard requirement of thickness swelling was 12%.

The effect of moisture content on the MOR and MOE properties is shown in Figures 4.6c-4.6d. The MOR at both dry and wet conditions and MOE increased with increasing moisture content of the flakes and reached the maximum value at the moisture content of 17%. Afterwards, these properties decreased with increasing the moisture content. The maximum values of dry MOR and MOE were 25.30 MPa and 3186.37 MPa, respectively, higher than the corresponding standard values of 13.8 MPa and 2000 MPa. In the case of wet MOR, the maximum value was achieved at a moisture content of 22% but this value was not significantly different.

Figure 4.6e shows the effect of moisture content on the internal bond strength values at both dry and wet conditions. The internal bond strength values exhibited the same trends as the MOR and MOE. The internal bond strength at the dry condition increased with increasing moisture content, reached the maximum value and then decreased with increasing moisture content. However, the maximum internal bond strength value at both dry and wet conditions was achieved at the moisture content of wood flake of 12%. The dry and wet internal bond strength values at 12% moisture content were about 6 and 3 times of the established standard values, respectively.

Polyisocyanates were transformed into polyureas at high temperatures in the presence of moisture. The reaction of pMDI with moisture (water) is shown in Figure 4.6.

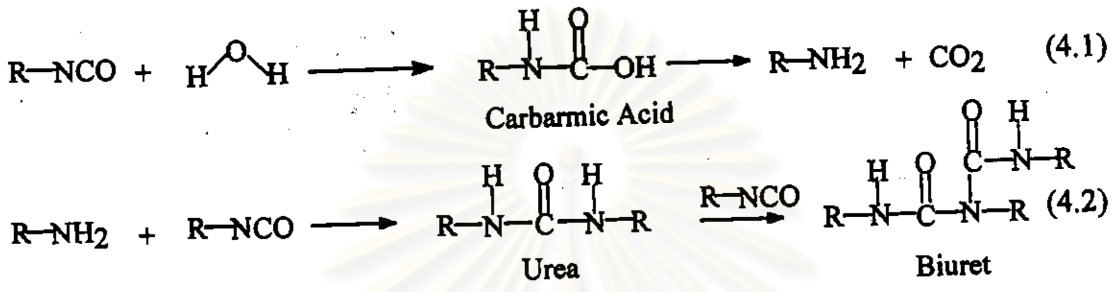


Figure 4.6 The reaction between isocyanate and water.

Moisture in the mat can be used advantageously and simultaneously can also cause problems. At high moisture content, it was easier to close the press quickly and the thickness of the board could be more easily controlled. The light weight presses could be built because the low pressure is required for consolidating the mats into boards. At high moisture content, particularly on the surfaces, the rate of heat transfer from the hot plates to the core of the mat was high. However, the cure time of the resin, particularly in the core of the board, could be impeded by the excess of moisture. The high mat moisture content of surfaces assisted in plasticizing the wood particles and provided the tight and hard surfaces. The various moisture contents and the distributions of moisture throughout the mat have a pronounce effect on the final particleboard density profile and the physical and mechanical properties. The problems resulted from a low mat moisture content are: higher water absorption in the board, rougher surfaces due to the decrease in the wood plasticization, slower heat transfer to the core, and slower closing time to stop at a given pressure [20].

Thus, the moisture content on the flake affected the processing of particleboard. Flakes with a high moisture content was easier to be compressed more than that with a low moisture content. However, there was the optimum range because the excess moisture content would cause some problems in the production steps. Moisture content of the flake had also affected the density of the particleboard as shown in Figure 4.8. The density of the particleboard increased with increasing flakes moisture content and reached the highest value at 12% moisture content and remained almost constant as increasing moisture content.

Table 4.9 Properties of particleboard prepared with various moisture contents.

Properties	Moisture content, %				
	2	7	12	17	22
MC, %	5.83 (1.24)	5.49 (0.27)	6.73 (0.47)	7.15 (0.18)	7.66 (0.72)
2-h WA, %	17.40 (3.00)	17.32 (4.04)	12.47 (1.39)	11.21 (2.57)	14.76 (2.37)
24-h WA, %	49.54 (5.61)	42.88 (5.28)	34.08 (2.39)	31.06 (3.85)	36.18 (3.47)
TS, %	4.22 (0.76)	5.60 (1.24)	4.45 (0.66)	3.73 (0.49)	3.52 (0.46)
MOR, MPa	12.54 (1.25)	18.00 (2.00)	23.34 (2.02)	25.30 (1.94)	23.71 (1.73)
MOE, MPa	1807.62 (182)	2334.52 (239)	2974.39 (298)	3186.37 (251)	3111.48 (205)
IB, MPa	1.07 (0.25)	1.07 (0.19)	2.09 (0.41)	1.48 (0.27)	1.09 (0.14)
2-h boil IB, MPa	0.23 (0.04)	0.26 (0.07)	0.45 (0.05)	0.34 (0.06)	0.36 (0.05)
2-h boil MOR, MPa	4.79 (2.15)	7.32 (3.47)	10.28 (4.73)	9.89 (4.56)	11.14 (5.05)

Values in parentheses are standard deviations.

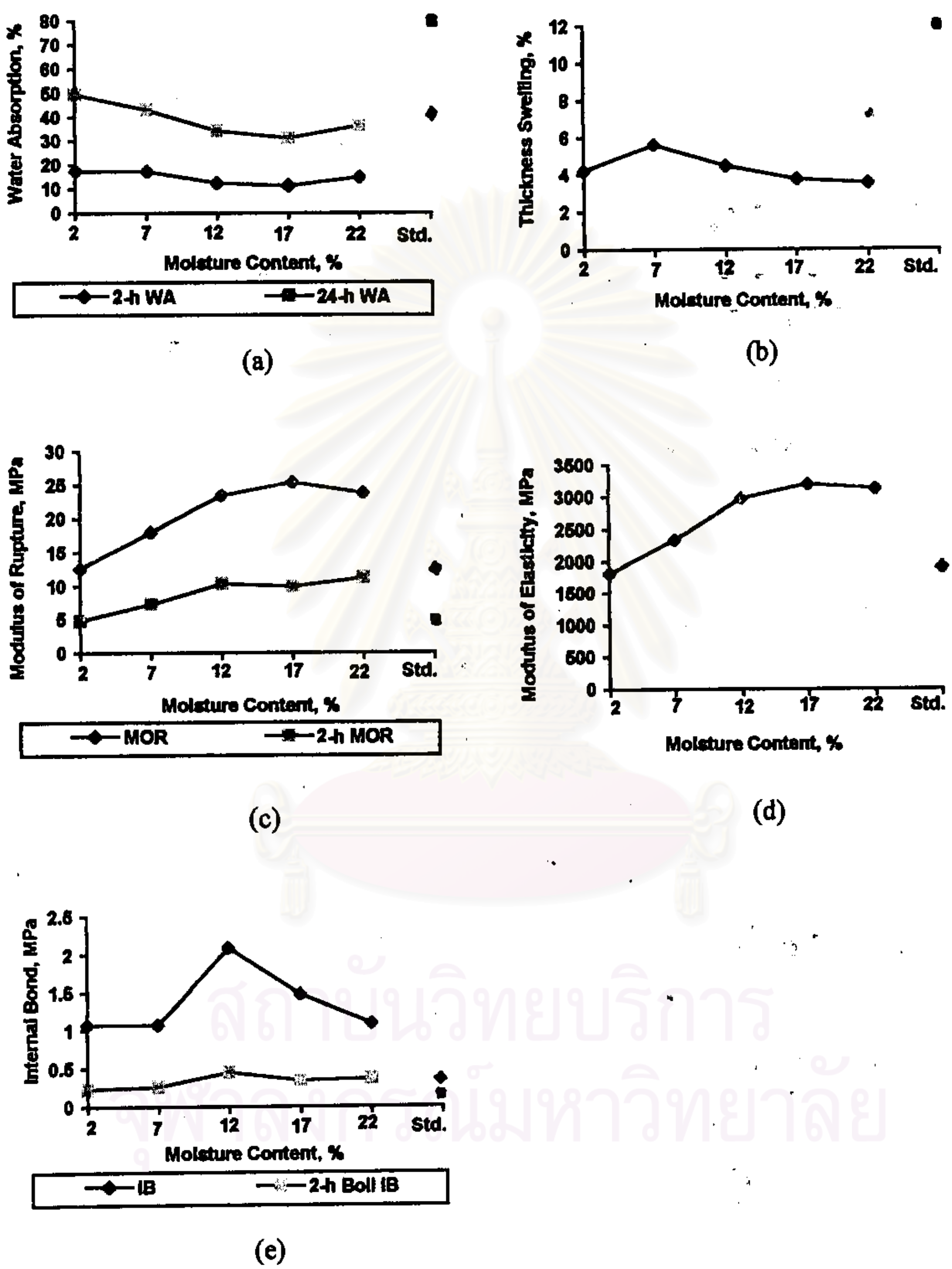


Figure 4.7 Effect of flakes moisture content on the properties of particleboard.

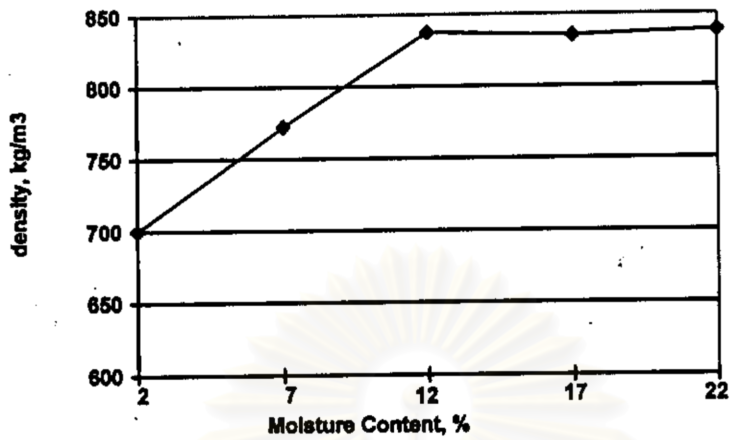


Figure 4.8 Density of the particleboard at various moisture contents.

4.9 Effect of Binder Types in Surface/Core Layers

In this part of the work, pMDI content of 7/5 (surface/core layers), cure time of 5 min. and cure temperature of 160 ^{0}C were used. The particleboard used pMDI was compared with the particleboard having phenol-formaldehyde resin (PF/PF) and pMDI in the core layer, phenol-formaldehyde on the surface layers (PF/pMDI). The results are shown in Table 4.10.

From Figure 4.9a, the water absorption properties of the particleboards using pMDI binder were better than those of PF and PF-pMDI binders. The 2-h water absorption value of the particleboard using PF resin was higher than the standard value. For the particleboard using pMDI in the core and PF in the surfaces, the absorption values (2-h, 24-h) were lower than the standard requirement. The thickness swelling values of the particleboards used pMDI were lower than those of PF and PF-pMDI (Figure 4.9b). For the particleboard using PF resin, the thickness swelling value was higher than those of the standard value.

From Figures 4.9c-4.9d, the MOR and MOE properties of the particleboard prepared from wood flakes of 7% moisture content with PF and PF-pMDI binders were slightly higher than that using pMDI binder. However, the particleboard prepared from the flake of 12% moisture content with pMDI binder, the MOR and MOE properties were better than those prepared from flake of 7% moisture content.

From Figure 4.9e, the particleboards prepared from the flakes of 7% moisture content, the particleboard using PF in the surfaces and pMDI in the core gave the highest internal bond strength at both dry and wet conditions. These values were higher than the standard values about 3 and 2 times, respectively. For the particleboard prepared from the flake of 12% moisture content with pMDI binder, these values were higher than the standard value of about 6 and 3 times, respectively. These results demonstrated that pMDI could be used well with high moisture contents of the wood flake and also gave the particleboard of better properties than that using conventional binders.

The platen pressure is in the same range as with conventional bonding agents, however, pressing times with pMDI binders could be 10 to 30% shorter than that with phenolic resins.[21, 42].

It was found that at low moisture content the particleboard prepared from pMDI had better performance than those prepared from the conventional binder. Although some properties were slightly lower than those prepared from PF binder. For the particleboard using pMDI in the core layer and PF in the surface layers, it exhibited good performance. Moreover, the use of the conventional binder in the surfaces, the conventional releasing agents could be used in the particleboard production. In the work of Hse, C., et al., [53] they reported that adding a small amount of polyisocyanate improves the performance of conventional binders considerably. From this work, the pMDI binder could be used very well with the rubber wood flake at high moisture content.

Table 4.10 Properties of particleboard prepared with various binder compositions.

Properties	Binder types in surface/core			
	pMDI1*	pMDI2**	PF/pMDI*	PF/PF*
MC, %	5.49 (0.27)	6.73 (0.47)	5.42 (0.28)	5.37 (0.22)
2-h WA, %	17.32 (4.04)	12.47 (1.39)	32.01 (2.89)	48.62 (2.81)
24-h WA, %	42.88 (5.28)	34.08 (2.39)	48.17 (5.13)	57.49 (2.81)
TS, %	5.60 (1.24)	4.45 (0.66)	12.09 (1.07)	15.57 (1.55)
MOR, MPa	18.00 (2.00)	23.34 (2.02)	19.99 (1.22)	19.41 (1.61)
MOE, MPa	2334.52 (239)	2974.39 (298)	2484.10 (128)	2385.20 (240)
IB, MPa	1.07 (0.19)	2.09 (0.41)	1.29 (0.27)	1.13 (0.18)
2-h boiled IB, MPa	0.26 (0.07)	0.45 (0.05)	0.29 (0.03)	0.19 (0.04)
2-h boiled MOR, MPa	7.32 (3.47)	10.28 (4.73)	8.32 (3.74)	9.34 (4.21)

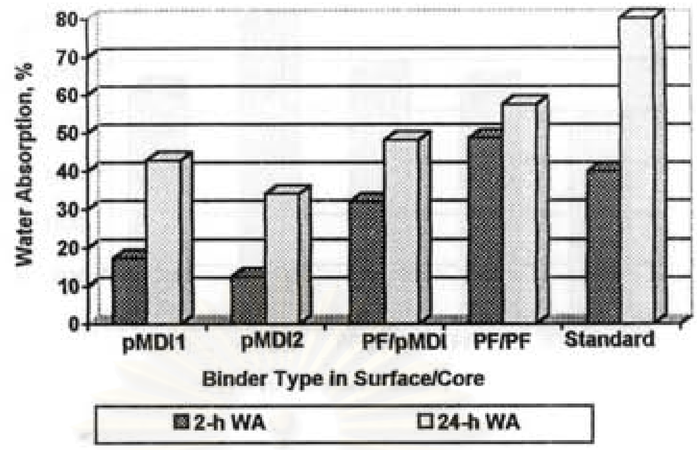
* = Particleboard prepared with 7% moisture content.

** = Particleboard prepared with 12% moisture content.

pMDI1 = Particleboard prepared with pMDI both surface/core.

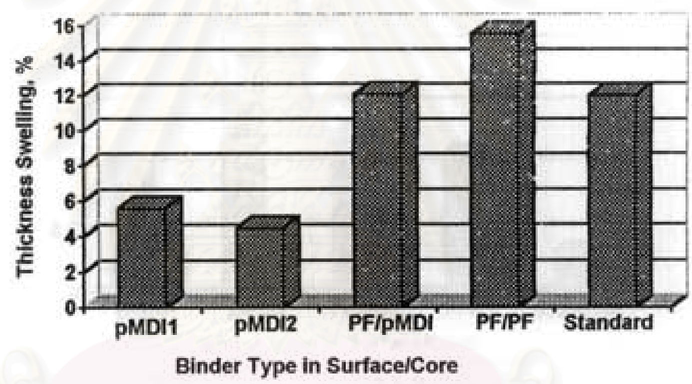
pMDI2 = Particleboard prepared with pMDI both surface/core.

Values in parentheses are standard deviations.



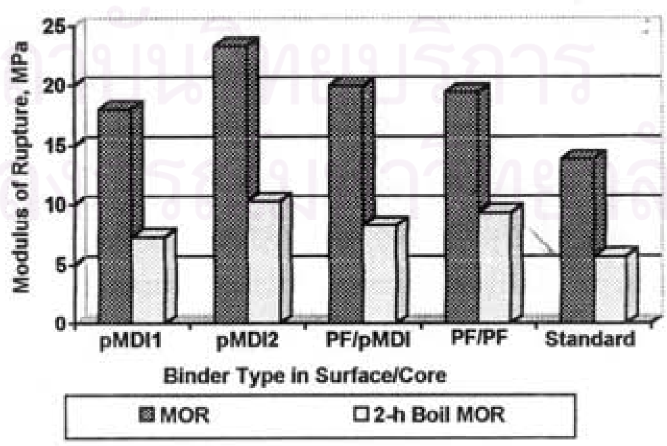
Water Absorption, %
0
10
20
30
40
50
60
70
80
pMDI1
pMDI2
PF/pMDI
PF/PF
Standard
Binder Type in Surface/Core
2-h WA
24-h WA

(a)



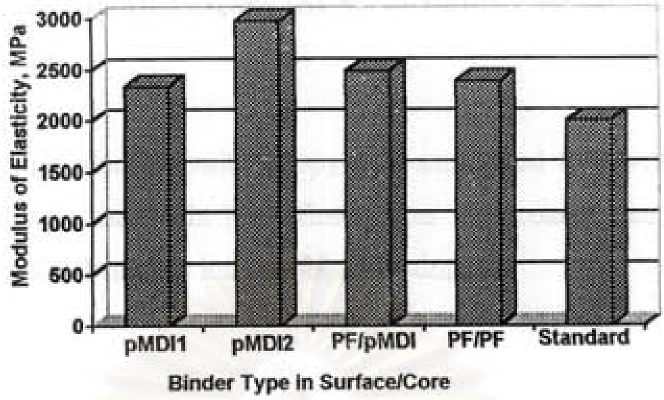
Thickness Swelling, %
0
2
4
6
8
10
12
14
16
pMDI1
pMDI2
PF/pMDI
PF/PF
Standard
Binder Type in Surface/Core

(b)

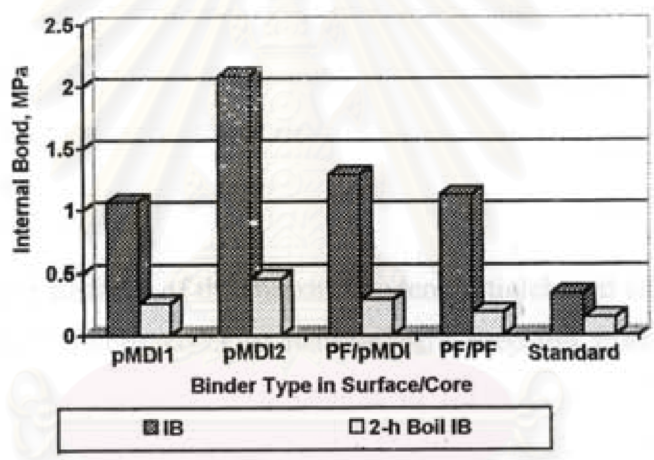


Modulus of Rupture, MPa
0
5
10
15
20
25
pMDI1
pMDI2
PF/pMDI
PF/PF
Standard
Binder Type in Surface/Core
MOR
2-h Boil MOR

(c)



(d)



(e)

Figure 4.9 Effect of binder type in surface/core on the properties of particleboard.

4.10 Scanning Electron Microscopy (SEM) of Rubber Wood Flakes and Particleboards

The scanning electron microscopy was employed to investigate the surface characteristics of raw materials both fine flakes and coarse one, and the fracture surface of the samples from the internal bond testing.

Figures 4.10 and 4.11 show the surface of fine and the coarse rubber wood flakes, respectively. The SEM micrograph of the coarse flakes at higher magnification (500X) is shown in Figure 4.12. From this figure, the pores in rubber wood flake are large to moderately large and visible to the naked eye. The pores are both of single and multiple types of two to four pores in the tangential and radial directions of the rubber wood. The vessel lines of the wood are conspicuous on tangential and radial surfaces. The surface characteristic of the coarse flakes was smooth and the fine flakes had rough surface.

The fracture surfaces of the rubber wooden particleboard are shown in Figures 4.13-4.16. The SEM micrographs of particleboard prepared from the flakes of 2% moisture content with the pMDI resin content of 7/5 (Figure 4.13) and 7% moisture content with the pMDI resin content of 7/3 (Figure 4.14) show the poor interfacial adhesion. The packing of the flakes were loose (or untight). Figure 4.16 shows that the fracture surfaces of particleboard prepared from flakes having 7% moisture content with the PF resin content of 7/5 (at 45% solid content), have the better packing characteristic. The packing of particleboard prepared from the flakes having a 12% moisture content with pMDI resin content of 7/5% (Figure 4.15) seems to be the best which was very tight. According to the mechanical properties, this packing behavior supported the results of mechanical properties testing that the particleboard prepared from the flakes having the 12% moisture content gave the highest internal bond strength. Furthermore, this confirmed the result of moisture content imposed on the compressibility of the flakes, the higher the moisture content, the greater the compressibility and the internal bond strength.

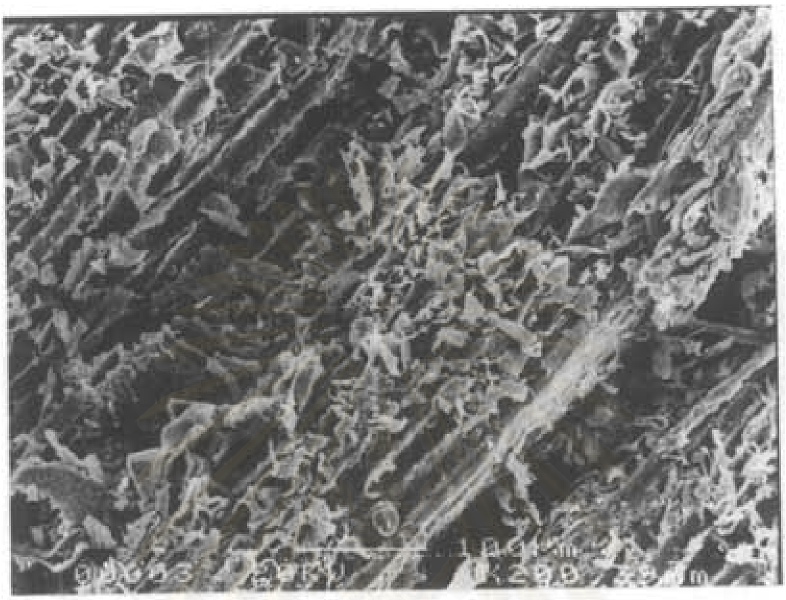


Figure 4.10 SEM micrograph of surface of fine rubber wood flake (200X).

Figure 4.11 SEM micrograph of surface of coarse rubber wood flake (200X).

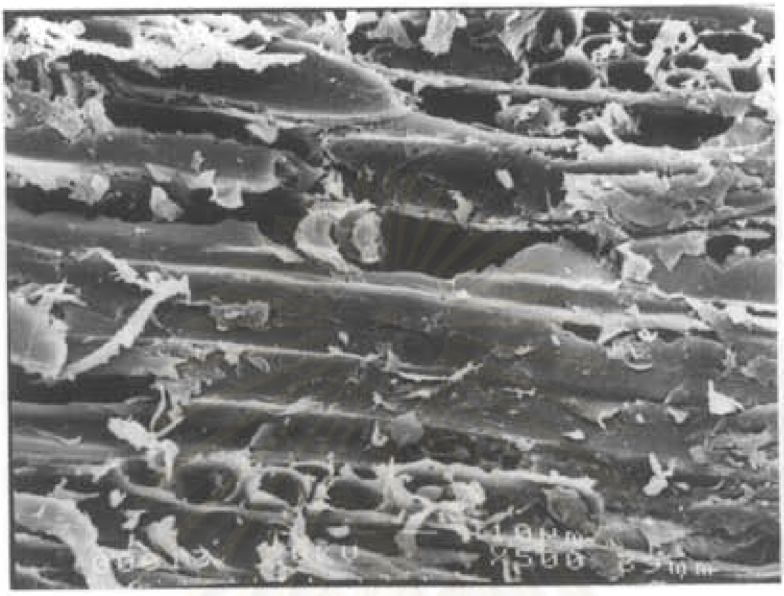


Figure 4.12 SEM micrograph of surface of coarse rubber wood flake (500X).

Figure 4.13 SEM micrograph of fracture surface of particleboard prepared from the flakes containing 2% moisture content with pMDI content of 7/5 (20X).

Figure 4.14 SEM micrograph of fracture surface of particleboard prepared from the flakes containing 7% moisture content with pMDI content of 7/3 (12X).

Figure 4.15 SEM micrograph of fracture surface of particleboard prepared from the flakes containing 12% moisture content with pMDI content of 7/5 (12X).

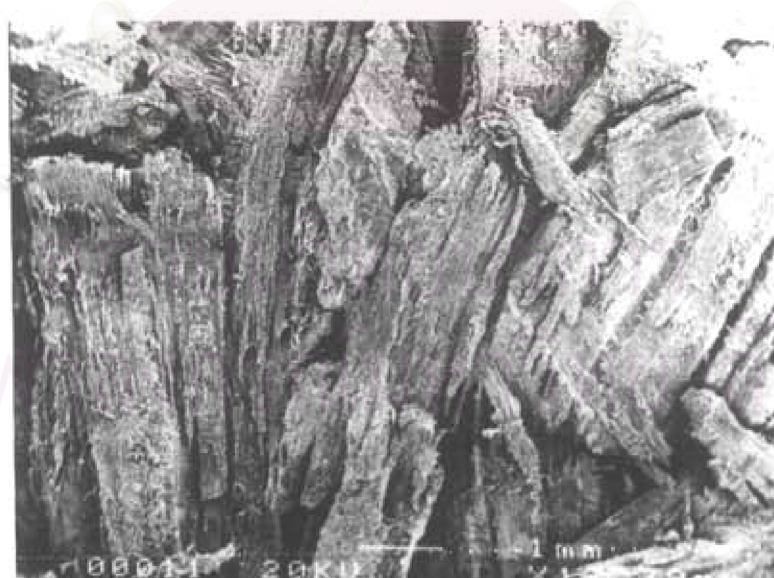


Figure 4.16 SEM micrograph of fracture surface of particleboard prepared from the flakes containing 7% moisture content with PF content of 7/5 (12X).

4.11 The Performance of pMDI Binder

The performance of the pMDI binder was investigated by the observation of the bondline of the flakes in the particleboard. The optical microscope was used in this study. The samples were stained with Lofton-Merritt stain which was affected by the amount of lignin in the flakes. If the sample is free of lignin, it appears colorless. If the sample contains high lignin, the stain turns blue.

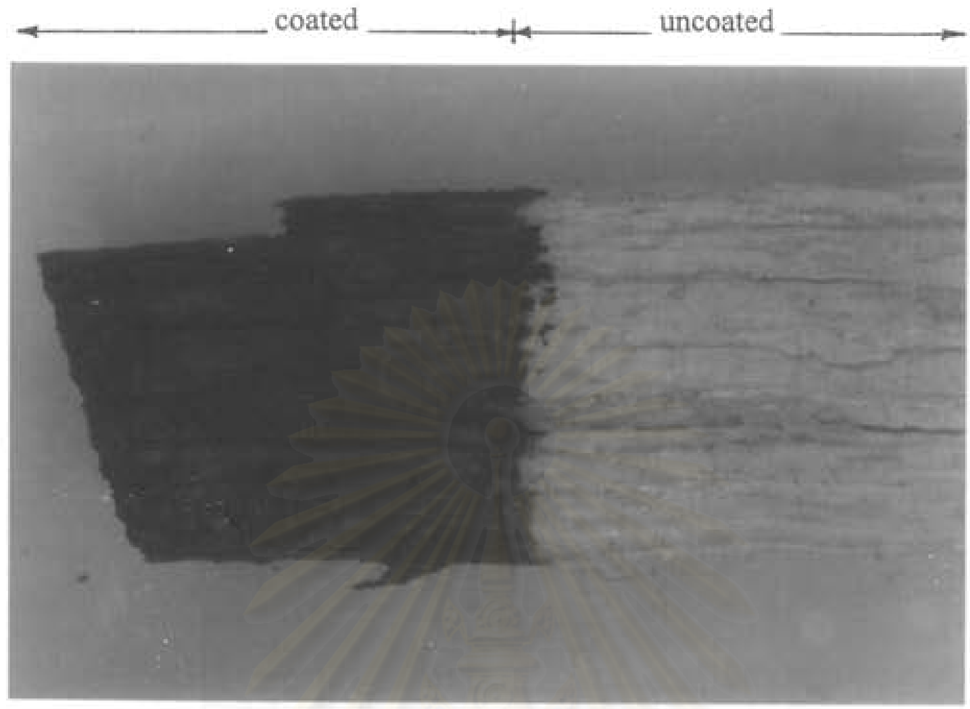
Figures 4.17a and 4.18a are the photographs of the flakes before staining. The flakes were treated with PF and pMDI resin and cured at 160 ^{0}C. The black line was the border of the area which was coated with binders before curing. From the figures, the flakes which was coated with PF resin gave the purple-red area (Figure 4.17a), while the flake which was coated with pMDI resin give the color similar to the rubber wood color or no change of color (Figure 4.18a).

The photographs of the flakes after staining are shown in Figures 4.17b and 4.18b. In the case of PF resin coated flake, the PF coated area could not be stained but the staining of uncoated area turned blue (Figure 4.17b). From Figure 4.18b, for the pMDI coated flake, the pMDI coated area could not be stained the same as the case of PF resin. Moreover, a part of the area above the black line (uncoated area) could not be stained. The size of the uncoated area is close to the coated area under the black line. The stained blue area appeared above this uncoated area. It can be explained that pMDI has better performance than PF resin, because under the same condition, pMDI could penetrate (or diffuse) to the uncoated area while PF resin could not.

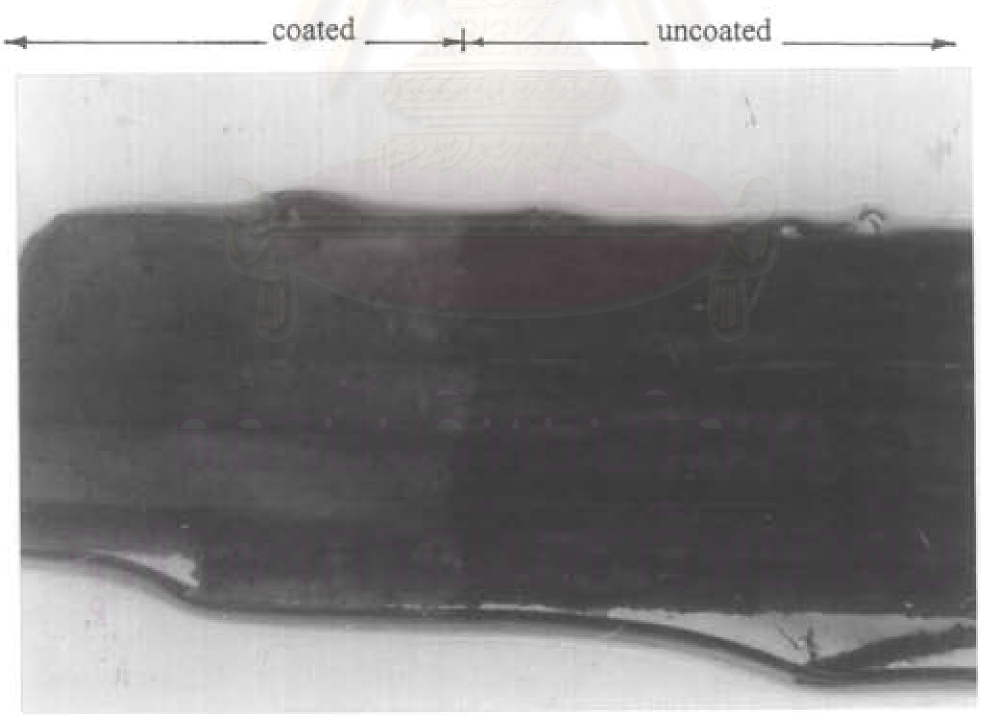
Figure 4.19 is the photographs of cured pMDI binder before and after staining. The cured pMDI binder after staining has the same color as the one before staining. This confirms that the cured pMDI could not be stained.

The optical photographs of the fracture surface of particleboards before and after staining are shown in Figures 4.20-4.23. Figure 4.20 is the photograph of the particleboard prepared from PF resin at resin content of 7/5 with a 7% moisture content. The stain of the fracture surface shows the darker blue color than the stain of fracture surface using pMDI binder (Figures 4.21-4.23). From Figure 4.20a, the intraparticle fracture surface area in the middle area has white (bright) color while the surrounding area has the purple-red color because the surrounding area was coated with PF binder. After staining, the white colored area disappeared and it was stained blue. The surrounding area (PF coated area) shows the bright area because it was not stained. The phenomena indicated that PF resin was only coated on the surface of wood, could not penetrated into the wood matrix.

Figures 4.21-4.23 are the photographs of particleboard prepared from pMDI binder at various pMDI contents and moisture contents. Figures 4.21a, 4.22a and 4.23 a are the photographs of unstained particleboards prepared at 7/3 resin content with 7% moisture content, 7/5 resin content with 2% moisture content, and 7/5 resin content at 12% moisture content, respectively. Figures 4.21b and 4.22b show both the stained blue and colorless areas. The intraparticle fracture surface areas were stained blue (dark area) but the interparticle fracture surface areas were colorless (bright area). From Figure 4.23a, a large intraparticle fracture surface area appears in the middle part but after staining (Figure 4.23b), this area becomes dark and bright blue. This can be explained that under high temperature, pressure and moisture content, pMDI binder could penetrate into the wood matrix. Thus, the intraparticle fracture surface areas which were occupied by pMDI gave the bright color and the unoccupied area gave the dark color. These phenomena were supported by the results of mechanical testing which gave the high value of the internal bond strength of particleboard using pMDI content of 7/5 and the flakes with the 12% moisture content.

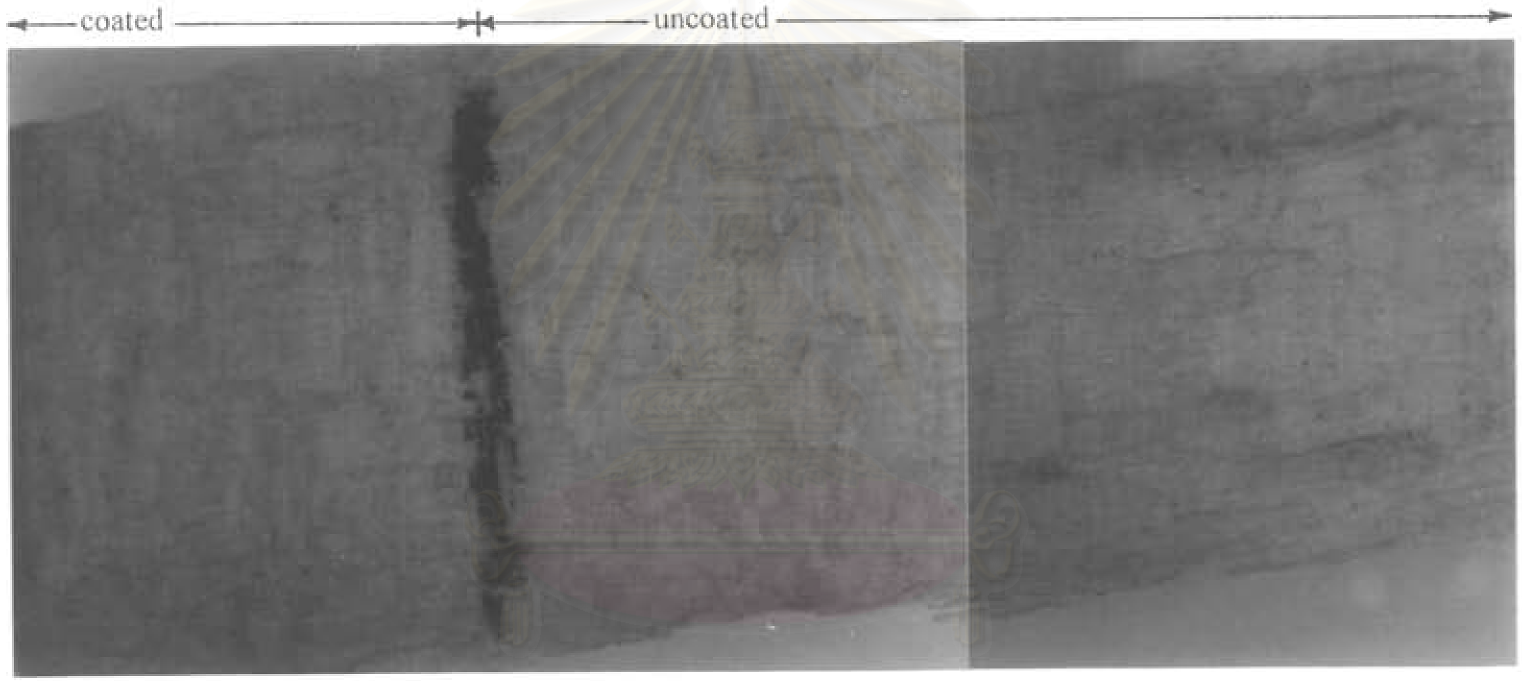


(a)

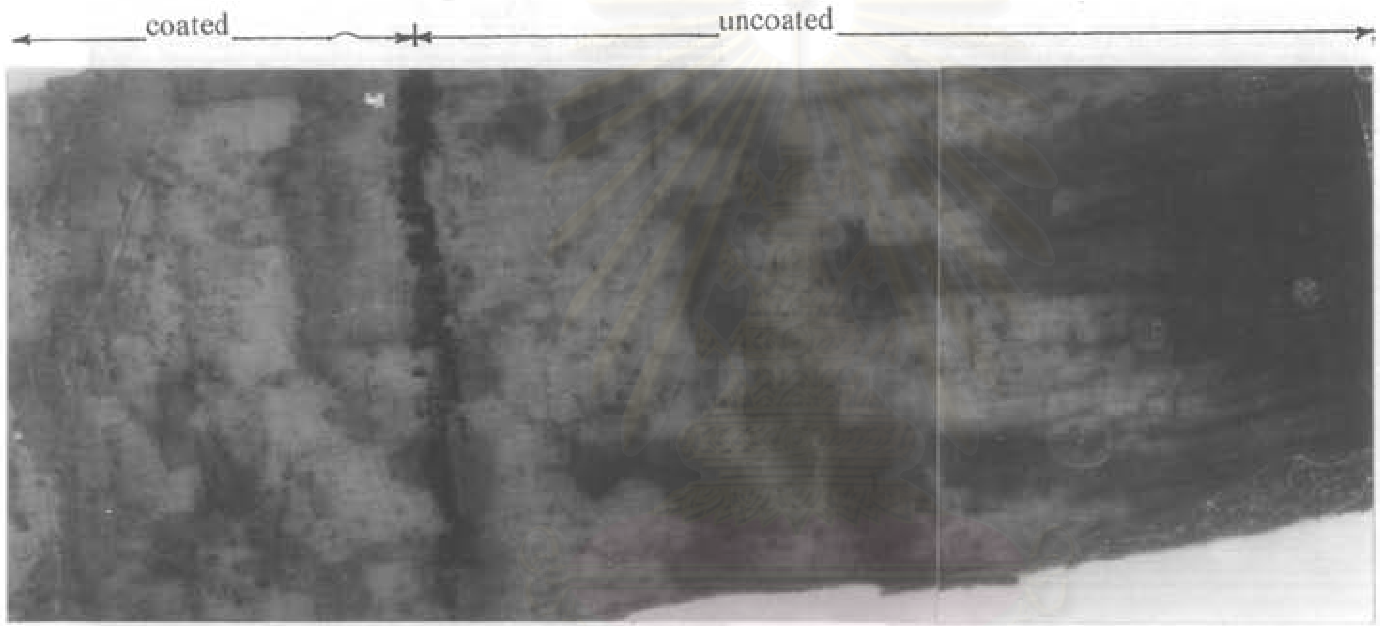


(b)

Figure 4.17 Photographs of PF coated rubber wood flake: (a) before staining and (b) after staining.

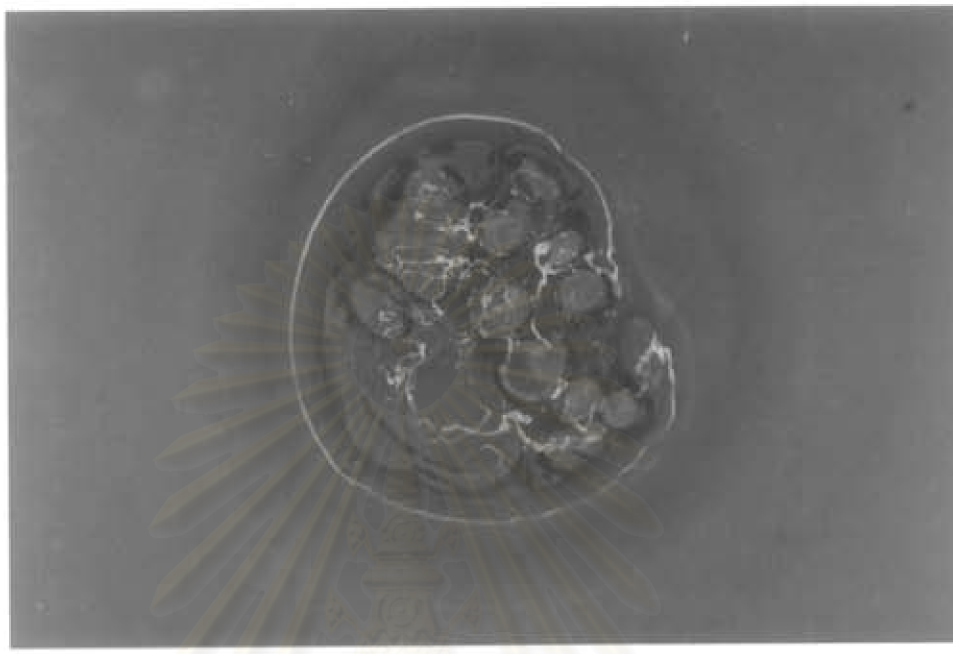


(a)

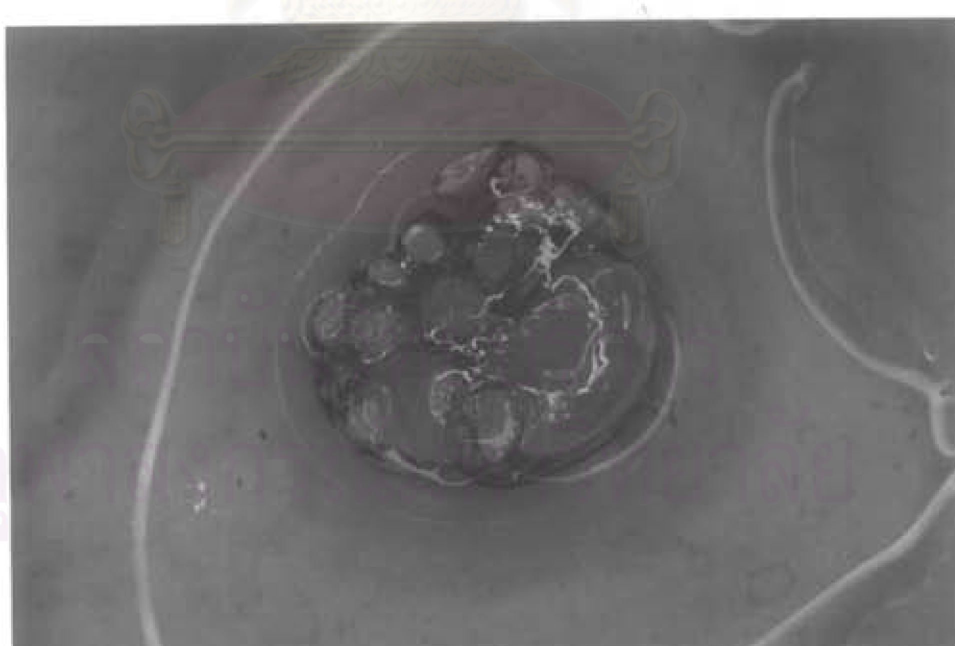


(b)

Figure 4.18 Photograph of pMDI coated wood flake: (a) before staining and (b) after staining.

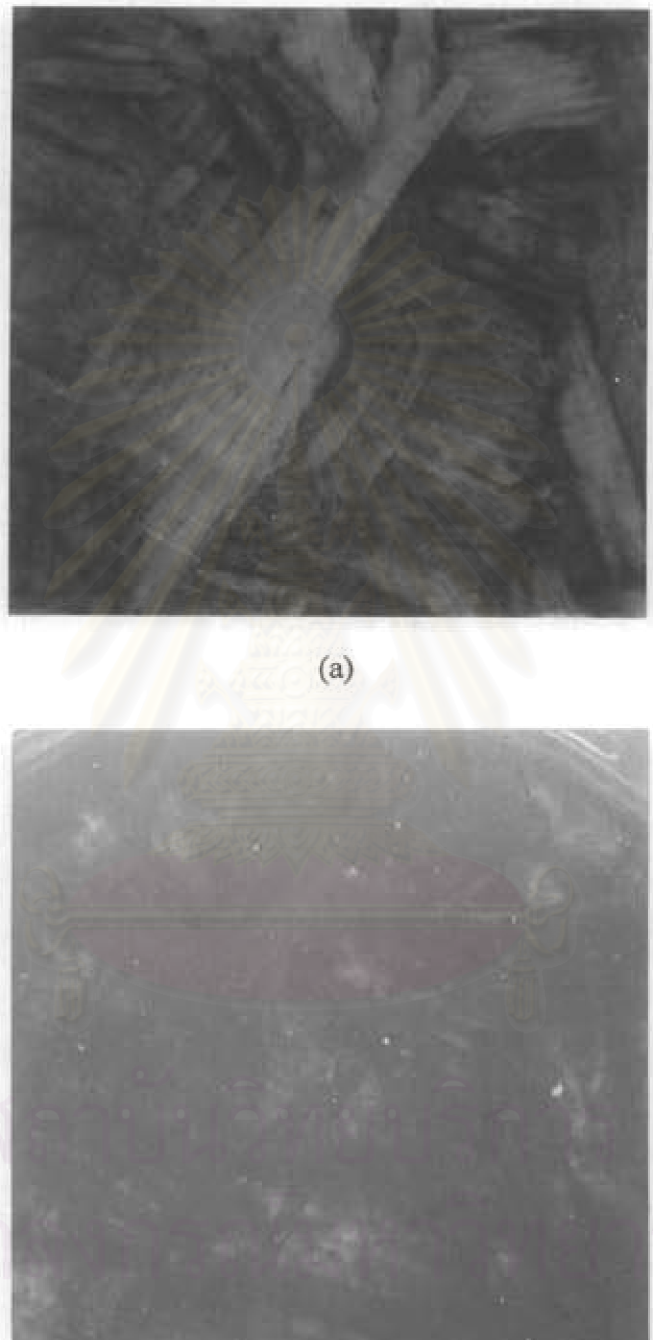


(a)



(b)

Figure 4.19 Photographs of cured pMDI binder: (a) before staining and (b) after staining.

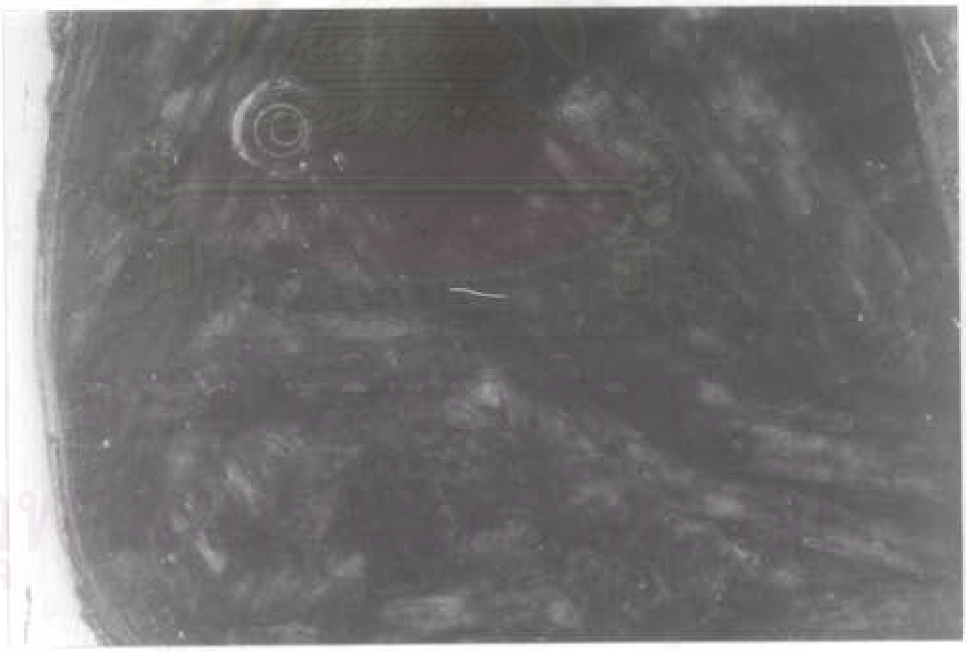


(a)

(b)

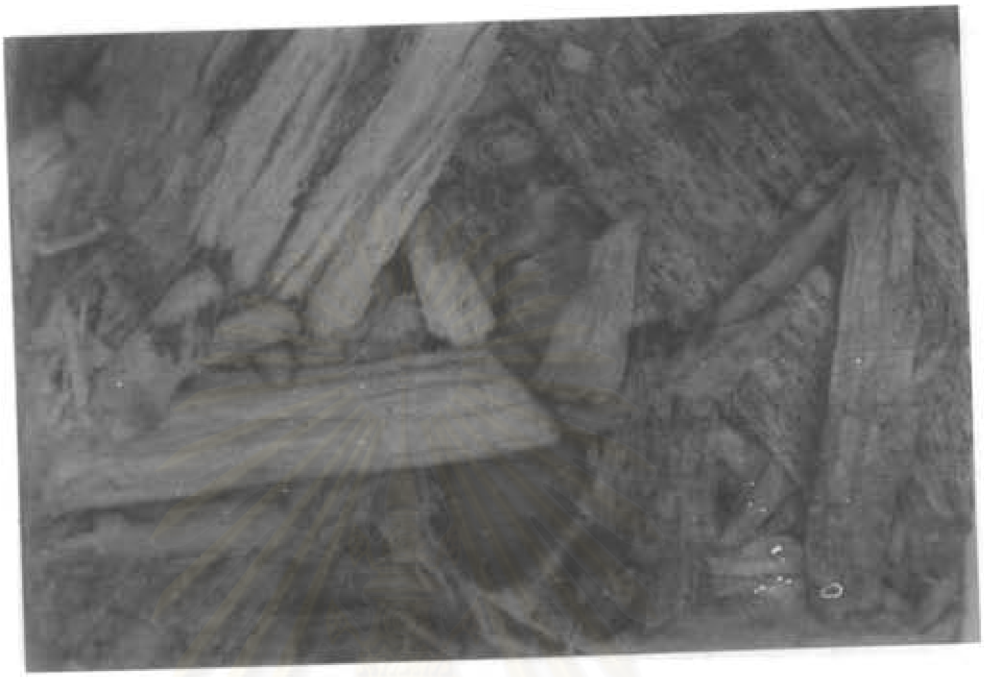
Figure 4.20 Photographs of the particleboard prepared from PF binder at resin content of 7/5 with a 7% moisture content: (a) before staining and (b) after staining.

(a)

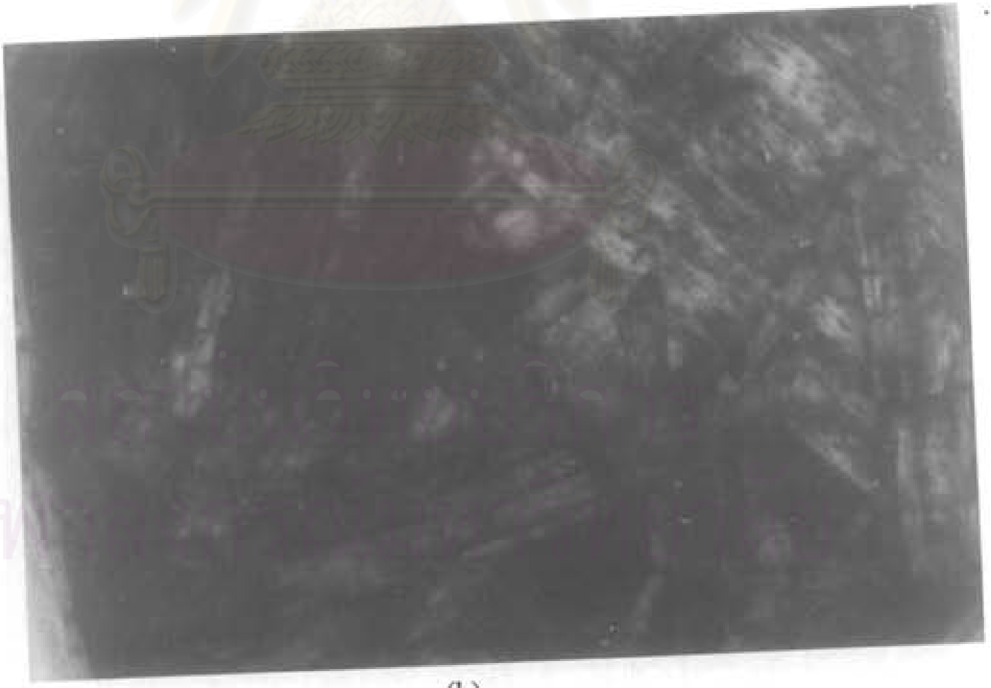


(b)

Figure 4.21 Photographs of the particleboard prepared from pMDI binder at the resin content of 7/3 with a 7% moisture content: (a) before staining and (b) after staining.

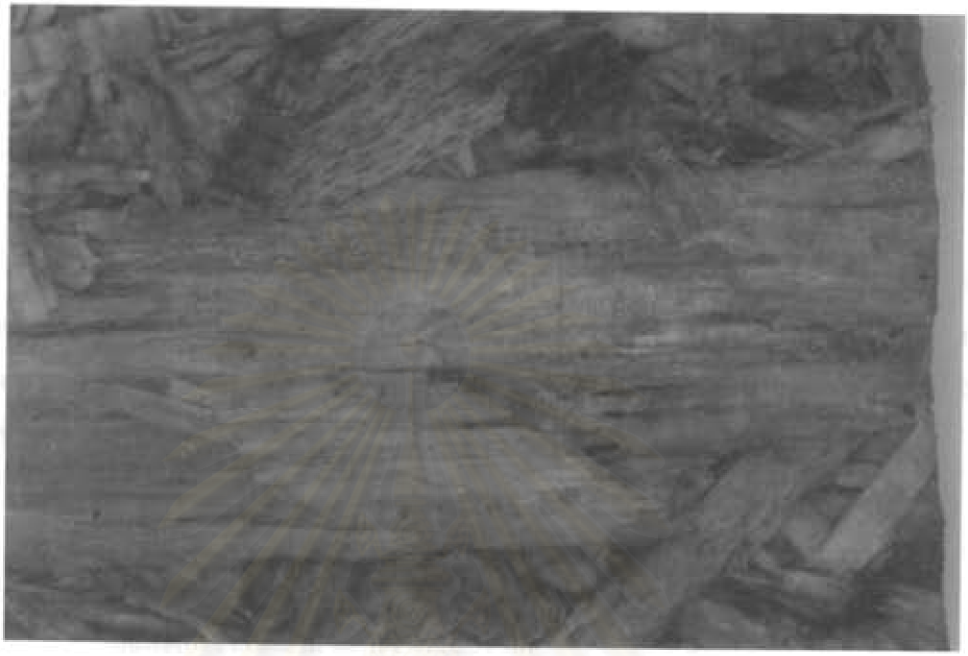


(a)



(b)

Figure 4.22 Photographs of the particleboard prepared from pMDI binder at the resin content of 7/5 with a 2% moisture content: (a) before staining and (b) after staining.



(a)

(b)

Figure 4.23 Photographs of the particleboard prepared from pMDI binder at the resin content of 7/5% with a 12% moisture content (a) before staining and (b) after staining.