CHAPTER 4

RESULTS AND DISCUSSION

Modified coconut wood can be defined as a wood polymer composites made from coconut and selected polymer. The coconut wood was impregnated by combination of styrene and methyl methacrylate and polymerized by heat treatment. The coconut wood modification improves its physical and mechanical properties including termite resistance.

4.1 Characteristic of coconut wood materials

In this study, only local coconut wood was studied. The physical and mechanical properties should therefore be characterized before studying. The results of characterization are presented in Table 4.1.

Table 4.1 Characteristics of coconut wood materials

Properties	A	B	C
Density (g/cm^3)	0.30-0.38	0.46-0.54	0.81-0.89
Water absorption (%)	175.00	110.31	43.06
Volumetric swelling coefficient (%)	10.10	9.64	6.18
Flexure stress (MPa)	33.01	70.11	109.22
MOE (MPa)	2637	4444	10254
Compression (MPa)	17.71	27.02	55.35

A = low density wood

B = medium density wood

C= high density wood

4.2 Effect of evacuating times on properties of impregnated samples

Evacuating time was the times that used to evacuate air from the void spaces of wood cells. It was assumed that, the longer evacuating time, the more void space free of air was obtained. Consequently, more monomer solution could penetrate into the wood cells. In this research, the evacuating time was varied from 0.25, 0.5, 1 hour for low density wood, 0.5, 1, 2 hours for medium density wood and 1, 2, 3 hours for high density wood. Results of these experiments were shown in Table 4.2 and illustrated in Figs. 4.1, 4.2 and 4.3.

Table 4.2 Properties of coconut wood polymer composites prepared by varying evacuating times.

Physical Properties	Evacuating times (hrs.)											
	Low density				Medium density				High density			
	0	0.25	0.5	1	0	0.5	1	2	0	1	2	3
Polymer Loading (%)	1.02	72.28	88.86	89.98	0.52	36.42	41.03	47.55	0.03	7.63	10.18	10.25
Density (g/cm^3)	0.34	0.61	0.66	0.66	0.48	0.66	0.68	0.72	0.87	0.94	0.96	0.96

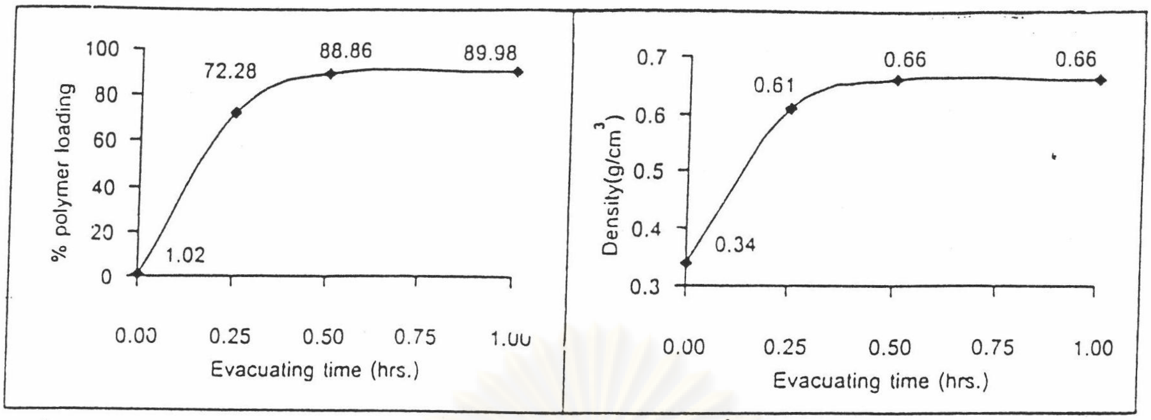


Fig.4.1 Effect of evacuating time on the polymer loading and density for low density materials

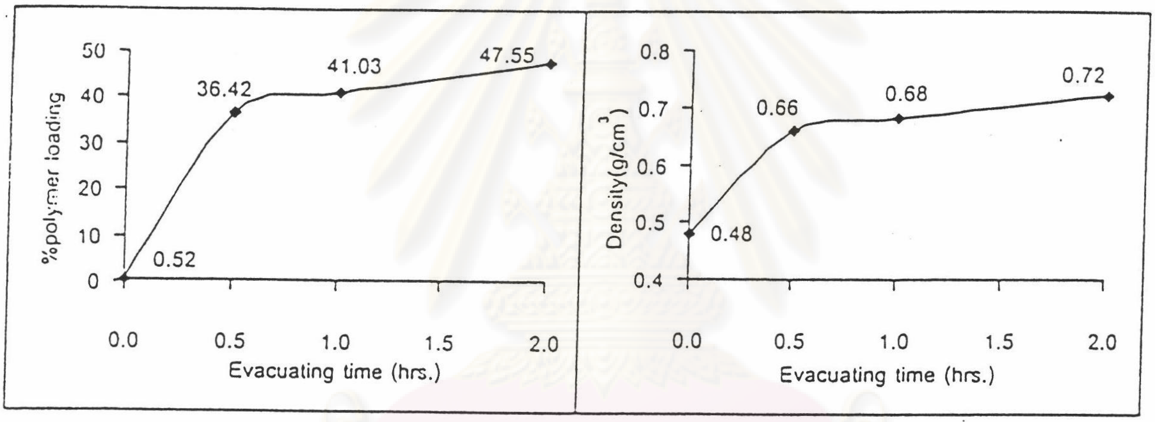


Fig.4.2 Effect of evacuating time on the polymer loading and density for medium density materials

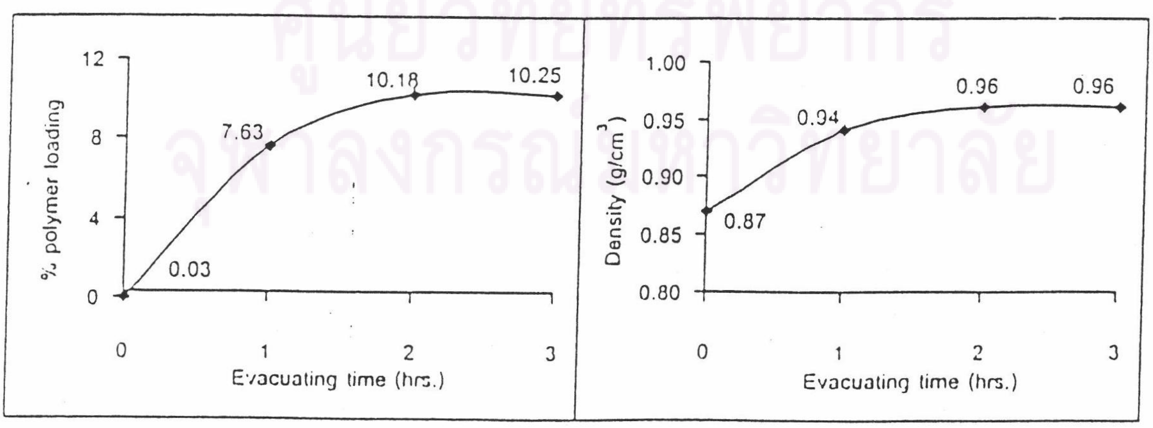


Fig.4.3 Effect of evacuating time on the polymer loading and density for high density materials

The results from Table 4.2 showed that samples with 0.5 and 1 hour evacuating time gave higher polymer loading and density than the samples with 0.25 hour evacuating time in low density materials. Polymer loading and density of samples with 0.5 and 1 hour evacuating time were not significant difference. Therefore, samples with 0.5 hour evacuating time was enough for use to study other effects.

In medium density materials, samples with 2 hours evacuating time gave the highest polymer loading and density. Therefore, samples with 2 hours evacuating time was used to study for other effects.

In high density materials, samples with 2 hours evacuating time gave higher polymer loading and density than samples with 1 hour evacuating time. Polymer loading and density of samples with 2 and 3 hours evacuating time were not significant difference. Consequently, samples with 2 hours evacuating time was enough for use to study for other effects.

4.3 Effect of soaking times on properties of impregnated samples.

Soaking time is the time which used for impregnation process. It is the periods used to soak the specimens so that monomer solution penetrate into empty wood cells and retained in there. The soaking times were varied from 0.5, 1, 4 hours for low, medium and high density wood . The other impregnation parameters were fixed as 0.5, 2, 2 hours evacuating time for low, medium and high density wood, respectively. The evacuating pressure was 500 mmHg and curing temperature was 70 °C. Results of these experiments are shown in Table 4.3 and illustrated in Figs. 4.4, 4.5 and 4.6

Table 4.3 Properties of coconut wood polymer composites prepared by varying soaking times.

Physical properties	Soaking times (hrs.)								
	Low density			Medium density			High density		
	0.5	1	4	0.5	1	4	0.5	1	4
Polymer loading (%)	88.86	97.50	99.62	47.55	55.15	63.84	10.18	13.02	16.95
Density (g/cm^3)	0.66	0.69	0.69	0.72	0.75	0.80	0.96	0.98	0.99

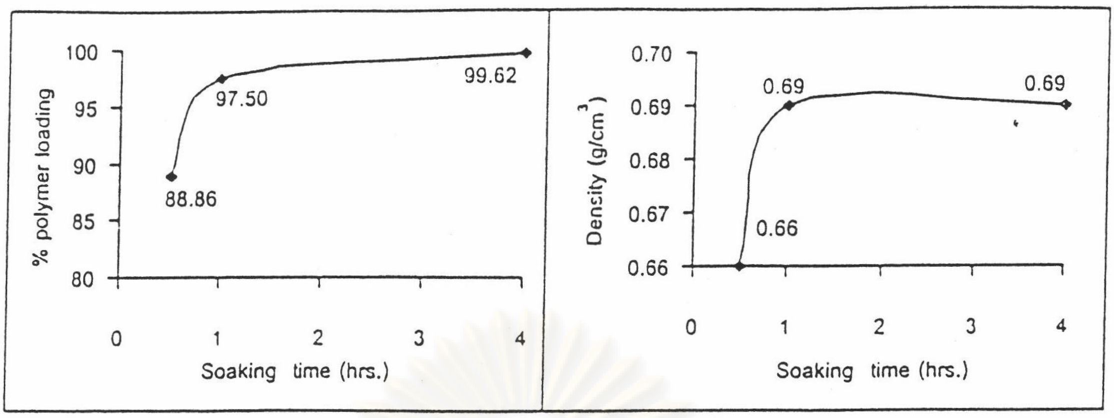


Fig.4.4 Effect of soaking time on the polymer loading and density for low density materials

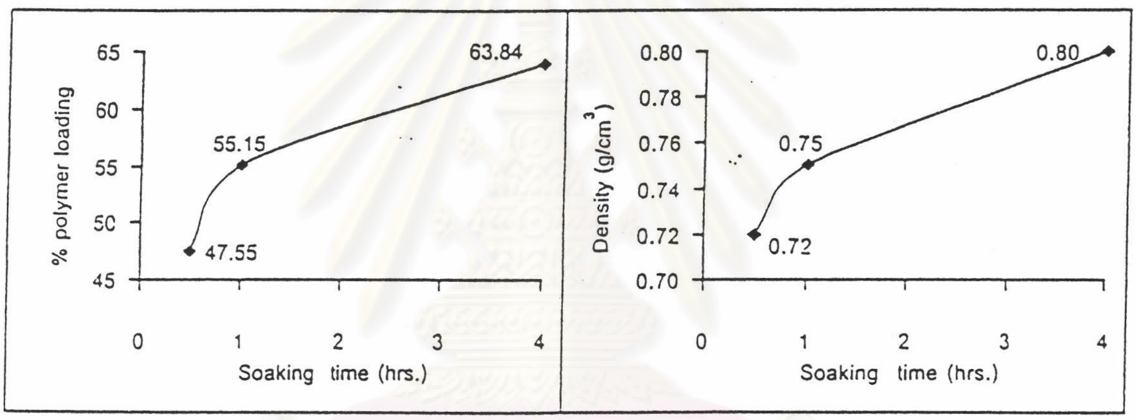


Fig.4.5 Effect of soaking time on the polymer loading and density for medium density materials

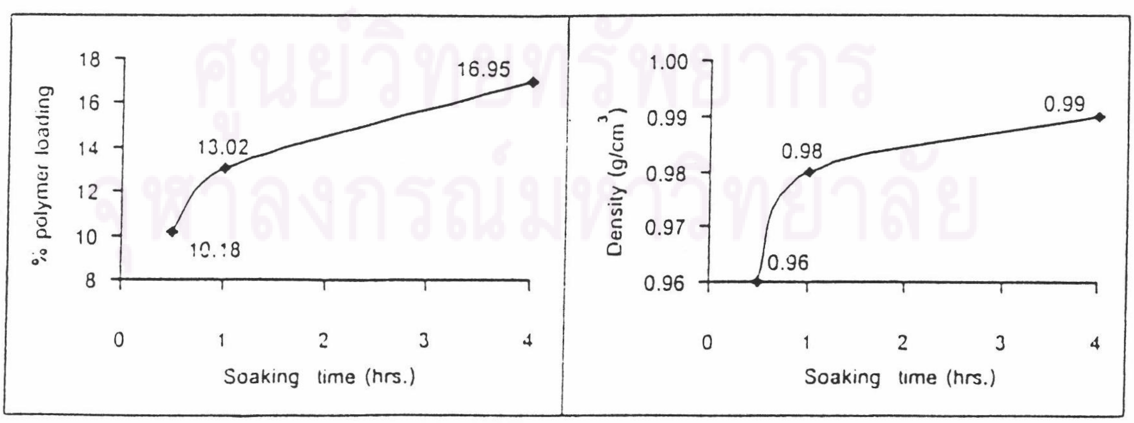


Fig.4.6 Effect of soaking time on the polymer loading and density for high density materials

From Table 4.3, it indicated that longer soaking time resulted in more polymer loading and density. For low density materials, samples with 1 hour soaking time gave higher polymer loading and density than those with 0.5 hour soaking time. Polymer loading and density of samples with 1 and 4 hour soaking time were not significant difference. Therefore, samples with 1 hour soaking time was enough for use to study for other effects.

For medium and high density materials, samples with 4 hours soaking time gave the highest polymer loading and density. Therefore, samples with 4 hours soaking time was used to study for other effects.

4.4 Effect of initiator content on properties of impregnated samples.

As the concentration of initiator increased, the properties of impregnated wood were expected to be changed. The initiator contents were varied from 1, 2, 3, 4 % by wt. in monomer solution. The other impregnation parameters were fixed as 0.5, 2, 2 hours evacuating time, 1, 4, 4 hours soaking time for low, medium and high density wood, respectively. The evacuating pressure was 500 mmHg and curing temperature was 70°C. Results of these experiments were shown in Tables 4.4, 4.5, 4.6 and illustrated in Figs. 4.7 and 4.8.

Table 4.4 Properties of low density coconut wood polymer composites prepared with various initiator contents.

Mechanical properties	Initiator content (% by wt.)				
	0 (unt.)	1	2	3	4
Polymer loading (%)	0	131.98	134.07	159.23	112.68
Density (g/cm^3)	0.35	0.82	0.87	0.85	0.78
Flexure stress (MPa)	28.4	61.2	66.2	58.8	55.4
MOE (MPa)	2429	4629	4590	4103	4381
Polymer loading (%)	0	94.30	71.67	74.23	119.84
Density (g/cm^3)	0.33	0.66	0.59	0.61	0.78
Compression (MPa)	17.34	21.94	23.84	23.60	24.00

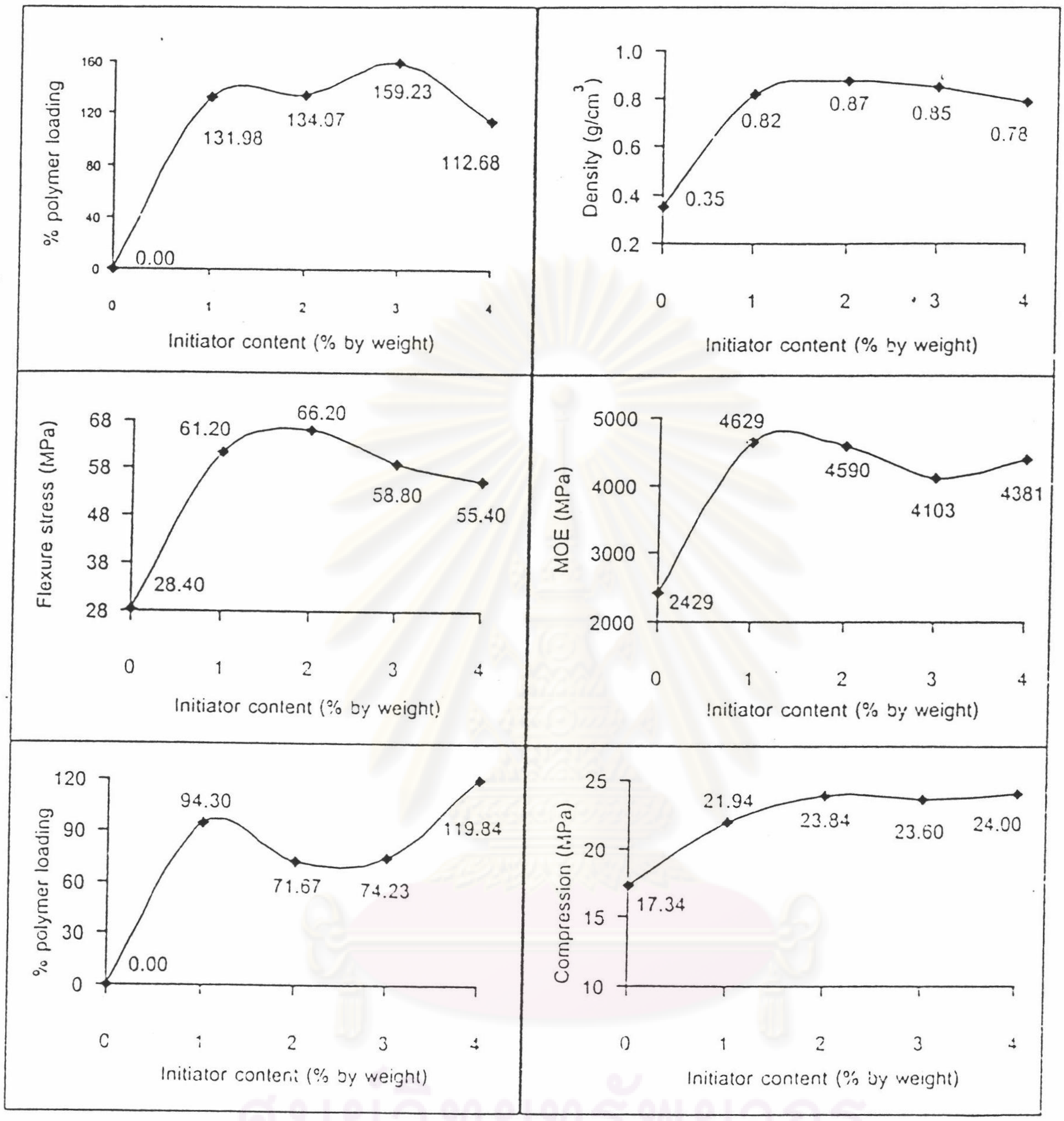


Fig.4.7 Effect of initiator content on the mechanical properties for low density materials

The results from statistical analysis showed that there were significant difference between untreated and treated low density wood. There were not significant difference between 2% and 3% by wt. of initiator in density, 1% and 2% by wt. of initiator in MOE, 1% and others by wt. of initiator in compression. There were significant difference between 2% and others by wt. of initiator in flexure stress. Consequently, 2 % by wt. of initiator was used to study for other effects.

Table 4.5 Properties of medium density coconut wood polymer composites prepared with various initiator contents.

Mechanical properties	Initiator content (% by wt.)				
	0	1	2	3	4
Polymer loading (%)	0	67.05	75.03	55.40	81.52
Density (g/cm^3)	0.47	0.81	0.81	0.77	0.87
Flexure stress (MPa)	70.7	83.2	83.6	84.1	73.0
MOE (MPa)	4106	5719	5724	5864	5630
Polymer loading (%)	0	68.59	56.93	59.04	60.66
Density (g/cm^3)	0.47	0.83	0.79	0.82	0.79
Compression (MPa)	27.84	43.24	49.00	42.26	47.00

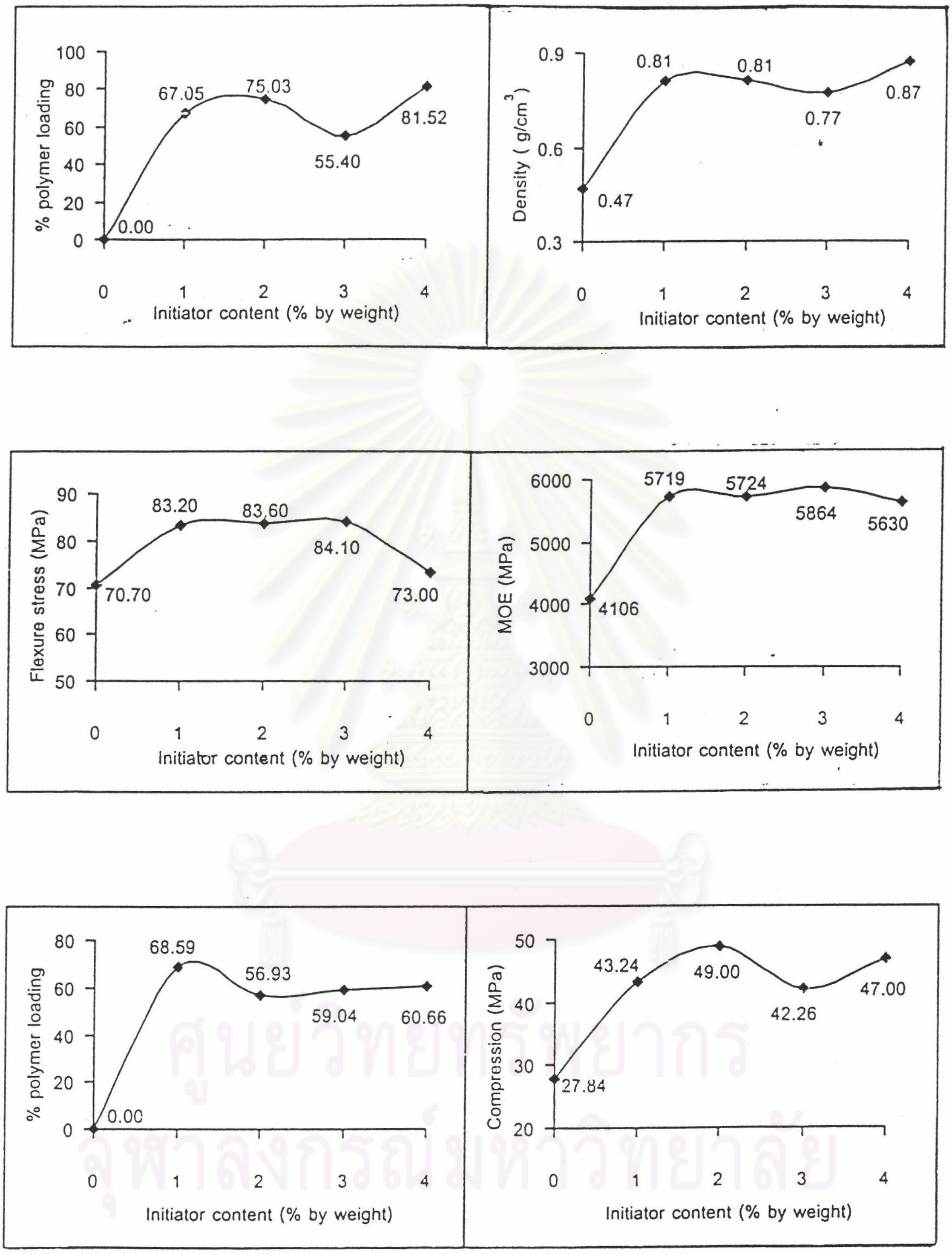


Fig.4.8 Effect of initiator content on the mechanical properties for medium density materials

The results from statistical analysis showed that there were significant difference between untreated and treated medium density wood. There were significant difference between 4% by wt. of initiator and others in density, 3% by wt. of initiator and others in MOE. There were not significant difference between 2% and 1% with 3% by wt. of initiator in flexure stress, 2% and 4% by wt. of initiator in compression. Therefore, 2% by wt. of initiator was used to study for other effects.

Table 4.6 Properties of high density coconut wood polymer composites prepared with various initiator contents.

Mechanical properties	Initiator content (% by wt.)	
	0	1
Polymer loading (%)	0	15.60
Density (g/cm^3)	0.84	0.98
Flexure stress (MPa)	112.8	113.7
MOE (MPa)	10257	10355
Polymer loading (%)	0	7.83
Density (g/cm^3)	0.83	0.88
Compression (MPa)	55.05	55.30

The results from statistical analysis showed that there were not significant difference in flexure stress, MOE and compression between 0% and 1% by wt. of initiator of high density materials. Consequently, preparation of high density coconut wood polymer composite was not achieved on the mechanical properties and it was not used to study other effects.

4.5 Effect of curing temperature on properties of impregnated samples

After impregnation process, samples were cured at the specific temperature which called curing temperature. The higher temperature, the better mechanical properties would be expected. Parameters of impregnation process are the same as parameters of 4.4 and 2% by wt. of initiator in monomer solution was used in the experiment. Curing temperatures were varied from 70°C and 90°C for low and medium density wood. Impregnated samples gave properties which presented in Table 4.7.

Table 4.7 Properties of coconut wood polymer composites prepared by varying curing temperature.

Mechanical Properties	Curing temperature (°c)			
	Low density		Medium density	
	70	90	70	90
Polymer loading (%)	120.70	126.05	74.98	72.23
Density (g/cm^3)	0.87	0.87	0.81	0.81
Flexure stress (MPa)	65.3	63.6	87.2	83.1
MOE (MPa)	4513	4571	5657	5720
Polymer loading (%)	80.50	84.66	54.55	57.26
Density (g/cm^3)	0.82	0.82	0.75	0.76
Compression (MPa)	24.60	24.00	49.60	49.00

The results from statistical analysis showed that there were not significant difference between 70°C and 90°C in density, flexure stress , MOE and compression of low and medium density materials. Because MEKP has low self accelerating decomposition temperature (60°C). Both 70°C and 90°C were lower temperature than boiling point of the monomers. So, 70°C was enough for use to study other effects.

4.6 Effect of ratios of styrene (ST) and methyl methacrylate (MMA) monomer on properties of impregnated samples

Combination of ST and MMA was expected to improve mechanical and physical properties of coconut wood. The ratios of ST/MMA were varied from 100/0, 70/30, 50/50, 30/70 and 0/100. Parameters of impregnation process were as follows : 0.5 hour evacuating time with 1 hour soaking time for low density wood and 2 hours evacuating time with 4 hours soaking time for medium density wood. The other parameters were 500 mmHg evacuating pressure, 2% by wt. of initiator in monomer solution and 70 °C curing temperature. Impregnated samples have the properties presented in Tables 4.8 and 4.9 and illustrated in Figs. 4.9 and 4.10.

Table 4.8 Properties of low density coconut wood polymer composites prepared from various ratios of ST/MMA.

Physical Properties	Ratio of ST/MMA				
	100/0	70/30	50/50	30/70	0/100
Polymer loading (%)	107.52	76.29	65.84	86.69	20.04
Density (g/cm^3)	0.74	0.57	0.57	0.61	0.42
Water absorption (%)	63.84	88.36	90.21	107.14	135.6
WRE (%)	63.52	49.51	48.85	38.78	22.51
S (%)	5.40	8.16	8.60	8.63	10.03
ASE (%)	46.53	19.21	14.85	14.55	0.69
Mechanical Properties					
Polymer loading (%)	134.07	123.82	84.77	135.72	63.01
Flexure stress (MPa)	66.2	40.0	35.6	55.5	43.6
MOE (MPa)	4534	2717	2541	3755	3137
Polymer loading (%)	71.67	123.97	79.44	74.74	20.48
Compression (MPa)	23.84	40.16	37.40	22.00	21.35

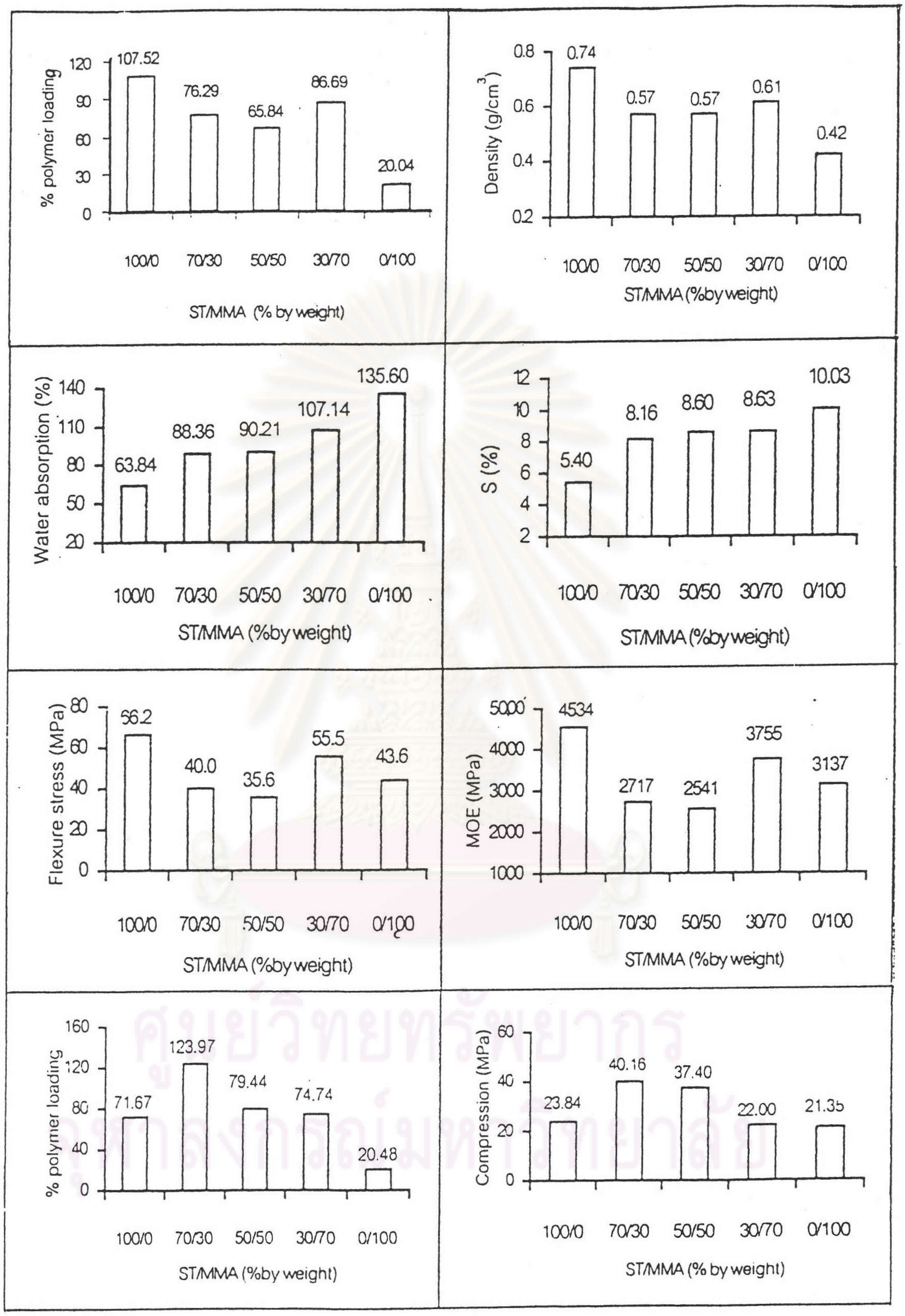


Fig.4.9 Effect of ratios of monomer on the physical and mechanical properties of low density materials

The results from statistical analysis showed that there were significant difference between 100/0 and others of ST/MMA in density, WA, S, flexure stress and MOE of low density materials. There were significant difference between 70/30 and others of ST/MMA in compression. So, 100/0 of ST/MMA was suitable to increase density, dimensional stability, flexure stress and MOE of low density wood and 70/30 of ST/MMA was suitable to increase compression of low density wood. In view of the fact that MMA has more polar than ST, therefore the more MMA, the more WA and S.

At 0/100 of ST/MMA or only MMA content, there was the least polymer loading and density because both MEKP and MMA have electron acceptor group, Both 70/30 and 50/50 of ST/MMA have lower styrene than 100/0 of ST/MMA, so they were lower in flexure stress and MOE than 100/0 of ST/MMA. The 30/70 of ST/MMA gave higher polymer loading than 70/30 and 50/50 of ST/MMA , so 30/70 of ST/MMA gave higher flexure stress and MOE than 70/30 and 50/50 of ST/MMA .

In case of compression, 70/30 of ST/MMA gave higher polymer loading resulted in the highest compression. Although 100/0 of ST/MMA gave higher polymer loading than 0/100 of ST/MMA but MMA gave better compression than ST. Therefore, 0/100 and 100/0 of ST/MMA were not significant difference in compression.

Table 4.9 Properties of medium density coconut wood polymer composites prepared from various ratios of ST/MMA.

Physical Properties	Ratios of ST/MMA				
	100/0	70/30	50/50	30/70	0/100
Polymer loading (%)	54.55	36.64	54.8	30.33	12.37
Density (g/cm^3)	0.75	0.68	0.74	0.67	0.54
Water absorption (%)	51.67	78.06	88.69	89.35	98.55
WRE (%)	53.16	29.24	19.60	19.00	10.66
S (%)	5.19	8.26	8.48	8.31	8.66
ASE (%)	46.16	14.32	12.03	13.80	1017
Mechanical Properties					
Polymer loading (%)	75.03	57.26	54.95	53.12	39.28
Flexure stress (MPa)	83.6	75.8	62.8	81.6	77.7
MOE (MPa)	5624	5313	5256	5545	5284
Polymer loading (%)	56.93	57.55	50.89	41.40	11.70
Compression (MPa)	48.00	48.70	39.90	39.60	35.77

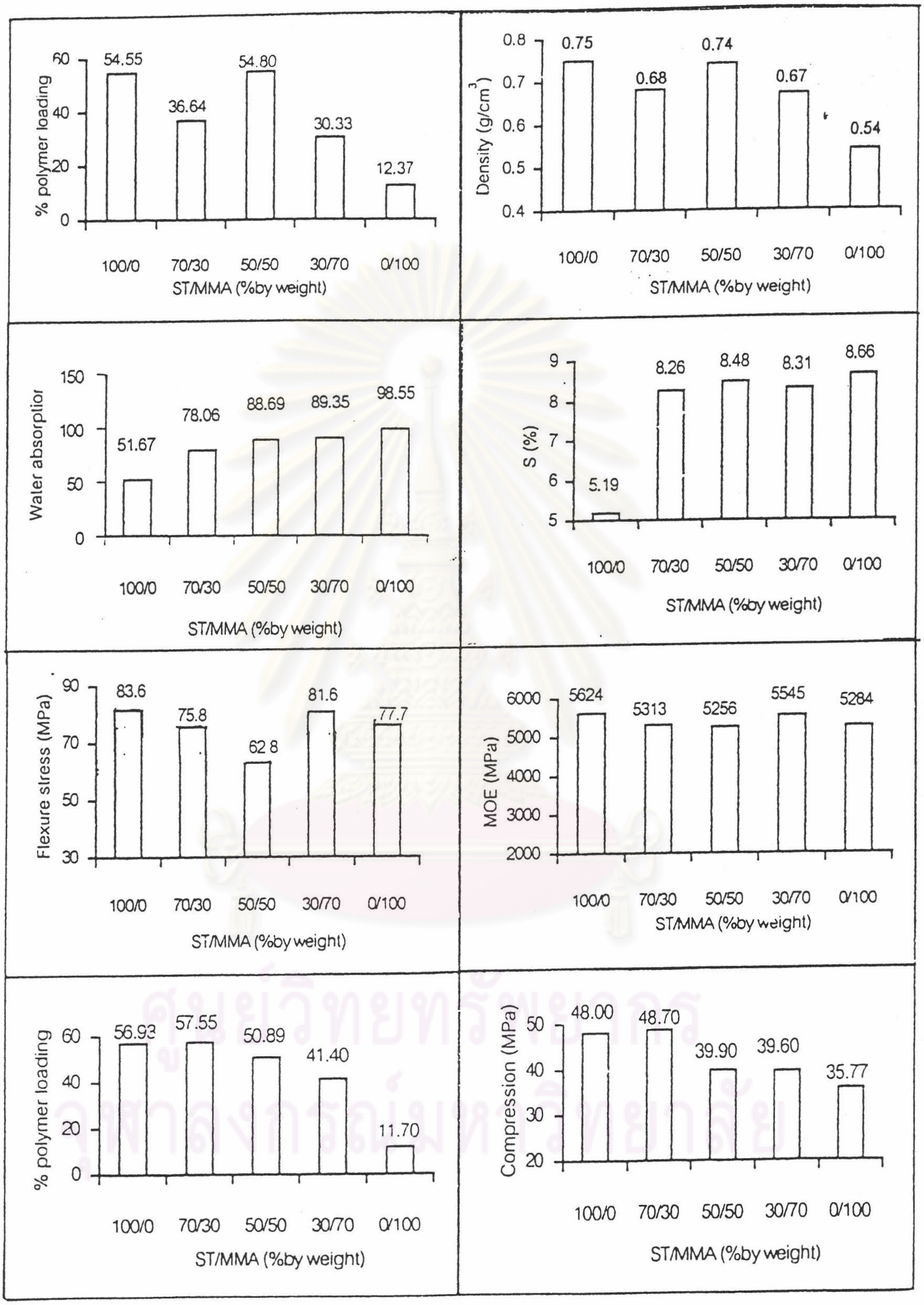


Fig.4.10 Effect of ratios of monomer on the physical and mechanical properties of medium density materials

The results from statistical analysis showed that there were significant difference between 100/0 and others of ST/MMA in density, WA and S. There were not significant difference between 100/0 and 30/70 of ST/MMA in flexure stress and MOE. There were not significant difference between 100/0 and 70/30 of ST/MMA in compression of medium density materials. So, 100/0 of ST/MMA was suitable to increase density, dimensional stability, flexure stress, MOE and compression of medium density wood. In view of the fact that MMA has more polar than ST, therefore the more MMA, the more WA and S. At 0/100 of ST/MMA or only MMA content, there was the least polymer loading and density because both MEKP and MMA have electron acceptor group. Both 70/30 and 50/50 of ST/MMA have lower styrene content than 100/0 of ST/MMA, so they were lower flexure stress and MOE than 100/0 of ST/MMA.

In case of compression, polymer loading of 100/0 and 70/30 of ST/MMA were not significant difference. So, they were not significant difference in compression. At 50/50, 30/70 and 0/100 of ST/MMA, they gave lower polymer loading than 70/30 of ST/MMA. So, they gave lower compression than70/30 of ST/MMA.

4.7 Effect of cross-linker on properties of impregnated samples

Cross-linker was expected to improve the properties of coconut wood polymer composites. Cross-linker was used at 50/50 of ST/MMA. Impregnated samples gave the properties presented in Table 4.10 and illustrated in fig. 4.11.

Table 4.10 Properties of low density coconut wood polymer composites prepared by varying cross-linker contents.

Mechanical Properties	Cross-linker content (% by wt.)		
	0	1	4
Polymer loading (%)	84.77	95.05	114.19
Density (g/cm^3)	0.63	0.68	0.69
Flexure stress (MPa)	35.6	47.6	47.8
MOE (MPa)	2541	3936	3475
Polymer loading (%)	79.44	96.77	102.51
Density (g/cm^3)	0.65	0.70	0.73
Compression (MPa)	37.40	43.26	45.80

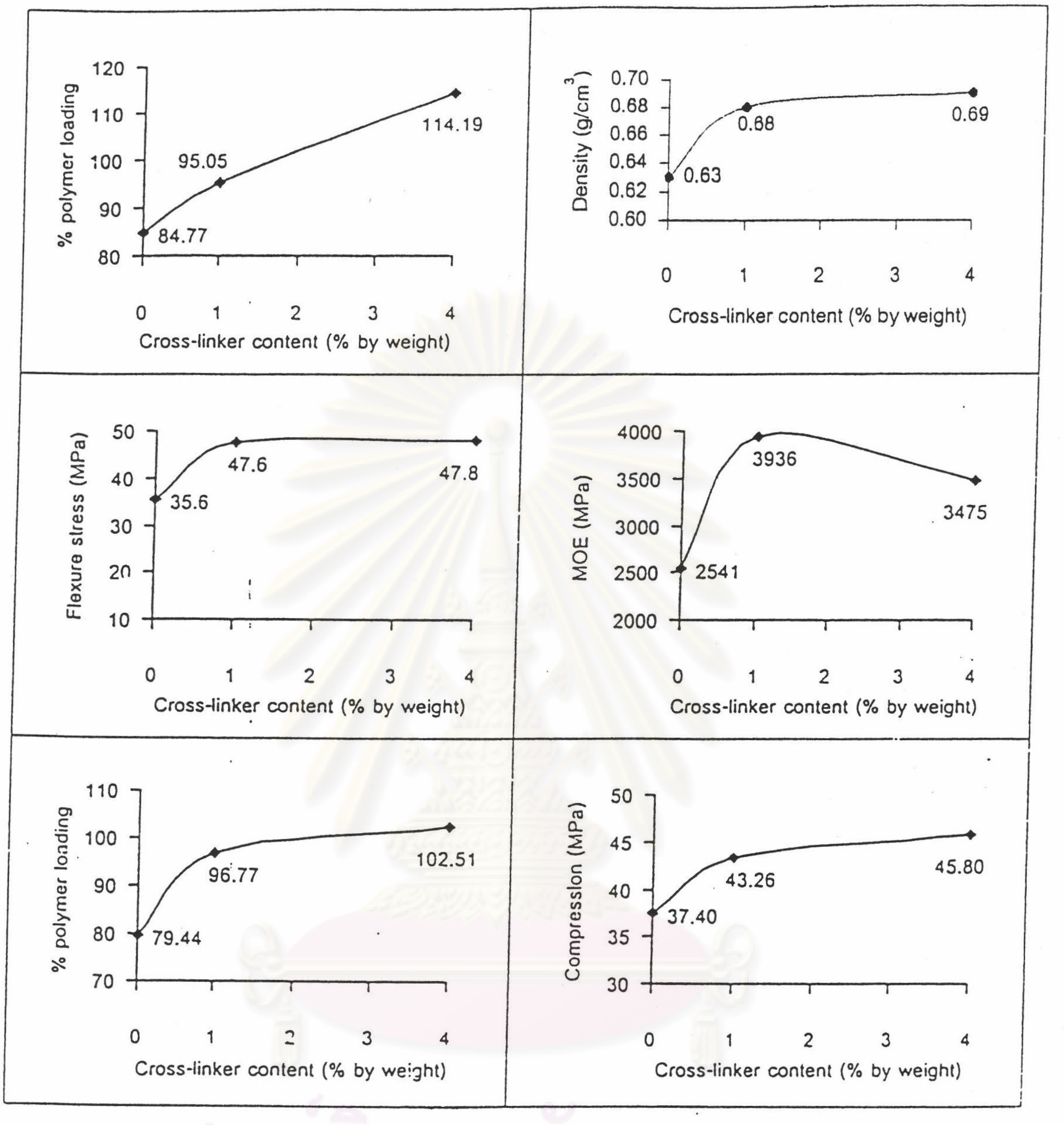


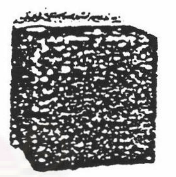
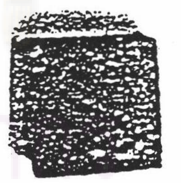
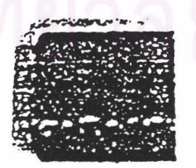
Fig.4.11 Effect of cross-linker on the mechanical properties of low density materials

The results from statistical analysis showed that there were significant difference between untreated cross-linker and treated cross-linker of impregnated samples. There were not significant difference in density, flexure stress and compression between 1% and 4% by wt. of cross-linker of impregnated samples. There were significant difference in MOE between 1% and 4% by wt. of cross-linker of impregnated samples. In view of the fact that cross-linker was used too much, the product was a typical hard, brittle cross-linked materials. Therefore, 1% by wt. of cross-linker of impregnated sample was suitable to improve the mechanical properties.

4.8 Evaluation of WPC specimens for resistance to termites

The annual loss in forest products of various kinds, resulting from deterioration by wood-boring insects such as subterranean termite. The damage occurs in standing trees, green saw logs, unseasoned lumber and other products and in seasoned material in storage and in use. Preservative wood with resin is one way to prevent damage from termites. In this experiment, coconut wood poly (styrene-co-methyl methacrylate) composites and untreated coconut wood were investigated under the same condition and the results were photographed for rating check. The results are shown in Table 4.11.

Table 4.11 The result of rating of termite attack

Ratio of ST/MMA	Low density		Medium density	
	Wood photograph	Rating	Wood photograph	Rating
Untreated wood		7		9
100/0		9		9
70/30		9		9
50/50		9		9
30/70		9		9
0/100		9		9
Teak	—			9

The data from Table 4.11 show. that low density materials were less damage than untreated low density coconut wood. Medium density materials were as damage as untreated medium density coconut wood and Teak. So, both styrene and methyl methacrylate are good resistance to termite attack.

4.9 Scanning Electron Microscopy (SEM) of WPC

The microstructure of wood-polymer composites (WPC) were examined by scanning electron microscopy of transverse section of the specimens. The microstructure of coconut wood cells are shown in figs. 4.12 and 4.13.

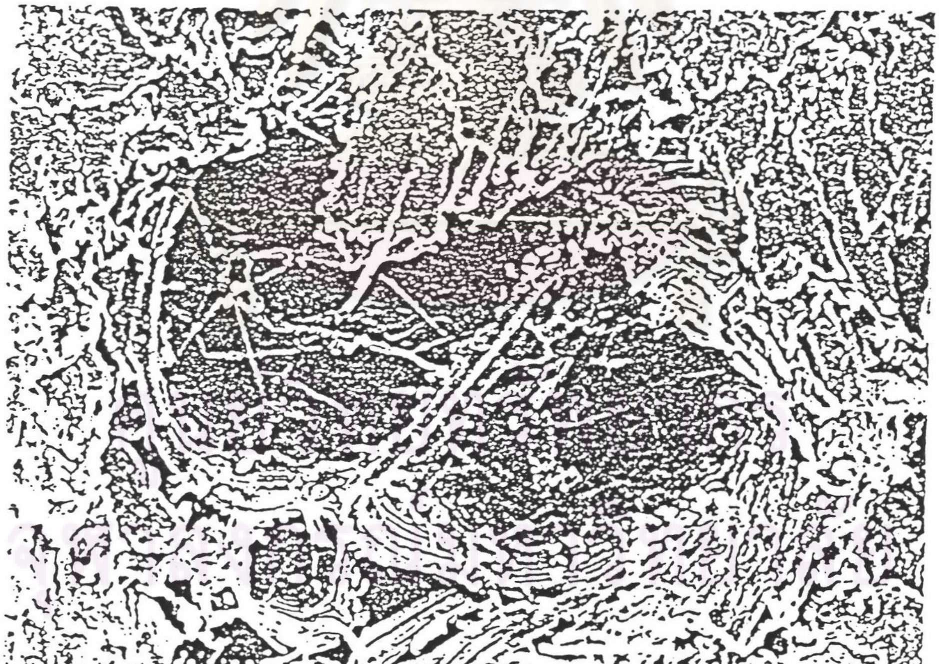


Fig. 4.12 SEM micrograph of transverse section of empty wood cells (350 x)

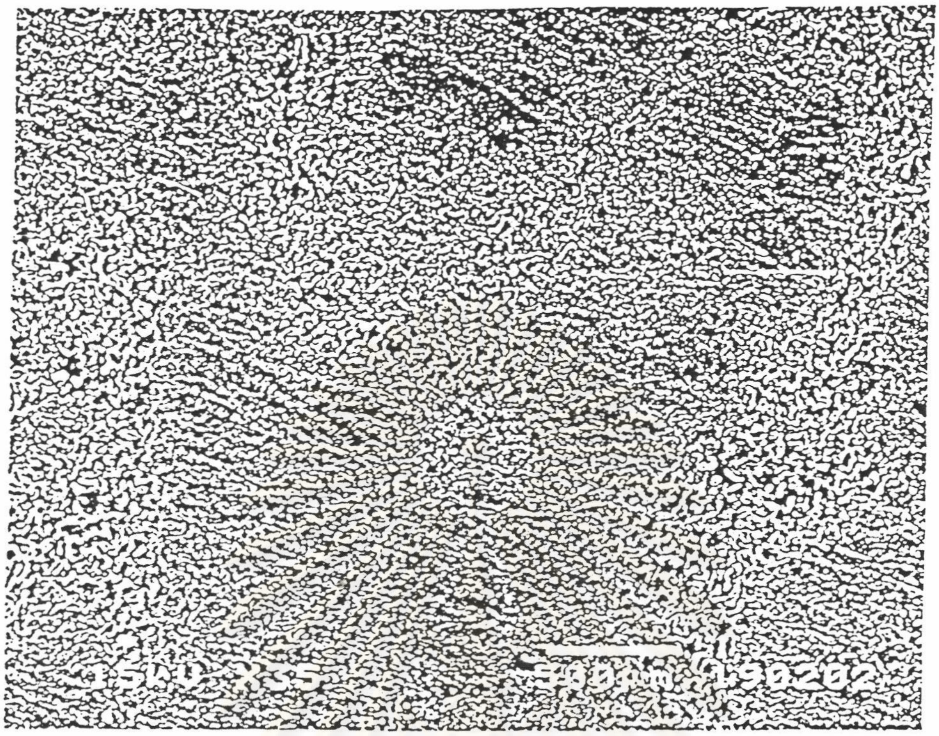


Fig.4.13 SEM micrograph of transverse section of polymer filled cells (35 x)

From figs. 4.12 and 4.13 the microstructure of untreated coconut wood cells revealed empty void spaces. In impregnation process, the empty wood cell were fully filled with polymer which resulted on the improvement of physical and mechanical properties of natural coconut wood.

4.10 Properties of coconut wood polymer composites

In this study, both physical and mechanical properties of coconut wood were improved as shown in Table 4.12.

Table 4.12 Comparison of the properties of coconut wood polystyrene and coconut wood poly(ST/MMA) composites with natural coconut wood, Teak, rubberwood

Properties	Low density			Medium density			Teak	Rubber wood
	Coconut wood	Coconut -ST	Coconut-ST/MMA (70/30)	Coconut wood	Coconut -ST	Coconut-ST/MMA (70/30)		
Density (g/cm^3)	0.30-0.38	0.74	0.57	0.46-0.54	0.75	0.68	0.65	0.63
WA (%)	175.00	63.84	88.36	110.31	51.67	78.06	28.19	37.00
S (%)	10.10	5.40	8.16	9.64	5.19	8.26	7.81	8.10
Flexure stress (MPa)	33.00	66.1	40.0	70.1	83.6	75.8	110.0	97.71
MOE (MPa)	2637	4534	2717	4444	5624	5313	8331	4553
Comp. (MPa)	17.71	23.84	40.16	27.02	48.00	48.70	75.45	41.50
Rating of termite attack	7	9	9	9	9	9	9	9
Mass loss (%)	10.2	3.9	3.9	8.0	2.7	2.6	1.16	-

The data from Table 4.12 show that the properties of both low and medium density wood could be improved by the formation of coconut wood polystyrene and coconut wood poly(ST-CO-MMA) composites. Both low and medium density coconut wood polystyrene gave better flexure stress , MOE, WA and S than those of low and medium density coconut wood poly(ST-CO-MMA). However, the compression was lower than those of low and medium density coconut wood poly(ST-CO-MMA) .

They indicated that medium density coconut-ST gave better density, S, MOE, compression but worse WA and flexure stress than rubberwood. Although mechanical and physical properties of coconut wood polymer composites were improved but they were still inferior than those of Teak which is classified as hardwood. Therefore, coconut wood polymer composites may be suitable to apply for light work such as furniture, cladding for ceiling , walls , vessel and others .