CHAPTER IV

RESULTS AND DISCUSSION

In this study, rubber wood-polymer composites made by impregnation of rubber wood with different acrylate monomer solutions under reduced pressure and using catalyst-heat curing technique to improve and enhance dimensional stability, mechanical properties, and biological resistance. The suitable conditions for preparation were investigated. Mechanical and physical properties of rubber wood-composites containing three kinds of acrylate were tested and compared with the natural rubber wood and other hardwoods.

4.1 Characteristic of natural rubber wood

In this study, the natural rubber wood and Red wood were studied. They were characterized for their physical and mechanical properties before study. The results of characterization are presented in Table 4.1.

Table 4.1 Characteristic of natural rubber wood and Red wood

Properties	Rubber wood	Red wood
Density (g/cm^3)	0.610	0.812
MOE (Mpa)	6219	5790
Flexure stress (Mpa)	92.8	82.00
Compression (N/mm^2)	42.15	82.30

- Average data from 5 specimens for each treatment. (2 replicates)

4.2 Effect of evacuating time on the polymer loading of WPC

Evacuating time is the time that used to evacuate air from the void spaces of wood cells. It was found that as the evacuating time increased, the void space free of air was correspondingly increased. So it improves the penetration of prepolymer solutions to the wood cells. In this study, the evacuating time was varied from 0.5, 1, 2 and 3 hours. The results of these experiments are shown in Table 4.2 and illustrated in Figure 4.1.

Table 4.2 Properties of rubber wood-polyacrylate composite prepared from various evacuating times

Polymer loading (%)	Evacuating time (hours)			
	0.5	1	2	3
2-HPA	49.99	57.23	57.86	56.03
BA	34.66	40.06	45.75	45.99
2-EHA	20.54	34.79	48.89	52.71

- Average data from 5 specimens for each treatment. (3 replicates)

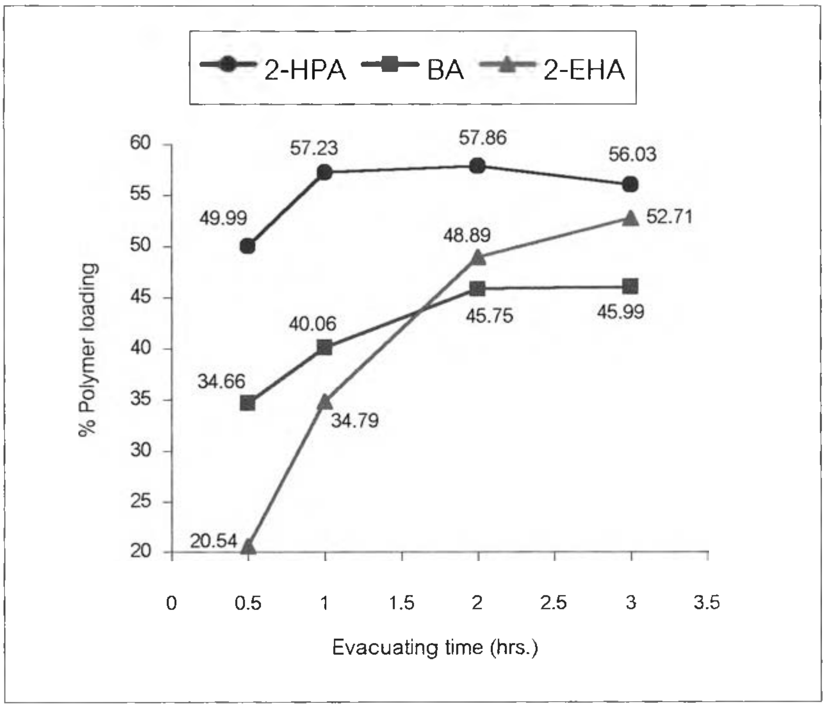

Figure 4.1 Effect of evacuating time on polymer loading of impregnated samples

The results of this experiment indicated that polymer loading was increased accordingly with soaking time. The longer evacuating time gave the ability to evacuate more air from the wood cells. Therefore, the prepolymer solutions have more opportunity to penetrate into the void space of wood cells. From Figure 4.1, BA and 2-EHA, polymer loading value during 2 and 3 hours evacuating time were not significant different while 2-HPA showed that at 1 hour was enough period to gave high polymer loading value. Then 2 hours evacuating time was chosen for the preparation of rubber wood-impregnated samples of BA and 2-EHA and 1 hour evacuating time was used for sample preparation using 2-HPA in the next experiment because of time and energy saving.

4.3 Effect of soaking time on the polymer loading of WPC

Soaking time is the duration that the specimens were soaked in the prepolymer solution. In this experiment, the evacuating time was fixed at 1 hour for 2-HPA and 2 hours for BA and 2-EHA. The soaking time was varied from 1, 2, 3, 4 and 6 hours. The properties of the impregnated samples are shown in Table 4.3 and illustrated in Figure 4.2.

Table 4.3 Properties of rubber wood-polyacrylate composite prepared from various soaking times

Polymer loading (%)	Soaking time (hours)				
	1	2	3	4	6
2-HPA	50.53	50.97	52.28	57.86	61.87
BA	28.16	34.29	42.87	45.75	46.21
2-EHA	37.09	36.13	41.76	48.89	48.35

- Average data from 5 specimens for each treatment. (3 replicates)

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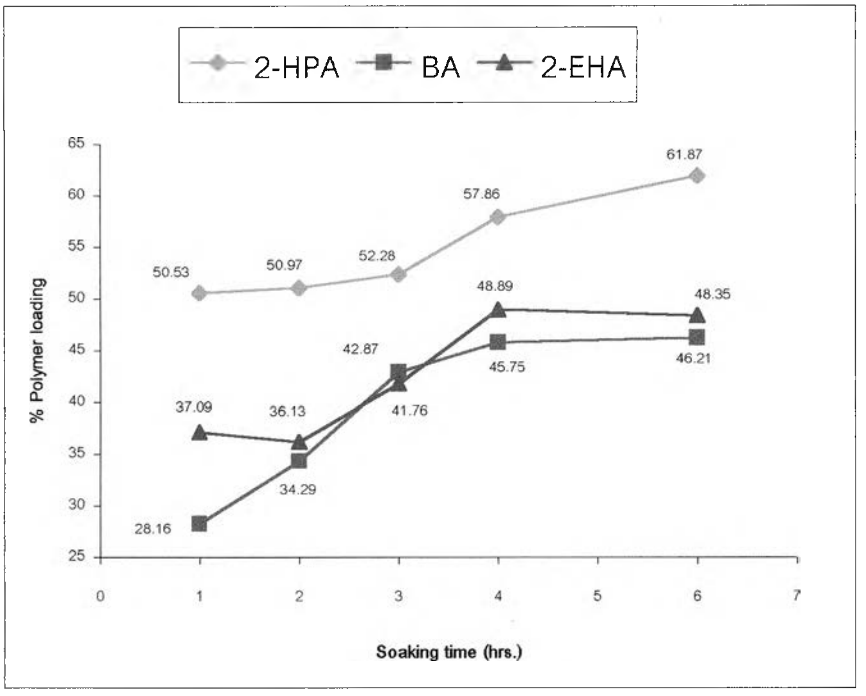


Figure 4.2 Effect of soaking time on polymer loading of impregnated samples

The results from Figure 4.2 indicated that polymer loading was increased accordingly with soaking time. However, there was no significant different of polymer loading between specimens obtained after 4 hours soaking time.

Soaking time at 4 hours is enough periods that treated samples showed high polymer loading. Therefore, 4 hours soaking time was selected to study for other impregnation parameters in the next experiment.

From Figures 4.1 and 4.2, sample preparation using 2-HPA gave higher polymer loading than others. It could be explained that hydroxyl group in the structure of 2-HPA could form hydrogen bond with cellulose in wood cells. Moreover, the structure of 2-HPA was smaller than those of BA and 2-EHA.

4.4 Effect of initiator content on the properties of WPC

As the concentration of initiator increased, the properties of impregnated samples were expected to be changed. The initiator contents were varied from 0.5, 1, 2 and 3 phr. Parameters of impregnation process were as follows: 2 hours evacuating time and 4 hours soaking time. The properties of impregnated samples were presented in Table 4.4 and illustrated in Figure 4.3.

Table 4.4 Properties of rubber wood-2-HPA composites prepared from various initiator contents

Physical properties	Initiator content (phr.)			
	0.5	1	2	3
Polymer loading (%)	48.56	51.37	51.49	51.87
Density (g/cm^3)	0.9353	0.9598	0.9643	0.9700
Water absorption (%)	24.00	22.90	22.63	22.18
Antiswell efficiency	38.10	39.20	39.28	39.22

Mechanical Properties	Initiator content (phr.)			
	0.5	1	2	3
Polymer loading (%)	51.41	56.68	57.00	52.26
MOE (MPa)	6177	6979	7364	7281
Flexure stress (MPa)	99.1	102.7	119.2	114.3
Polymer loading (%)	57.52	60.55	69.47	54.38
Compression (N/mm^2)	54.12	63.95	75.02	67.70

- Average data from 7 specimens for each treatment. (3 replicates)

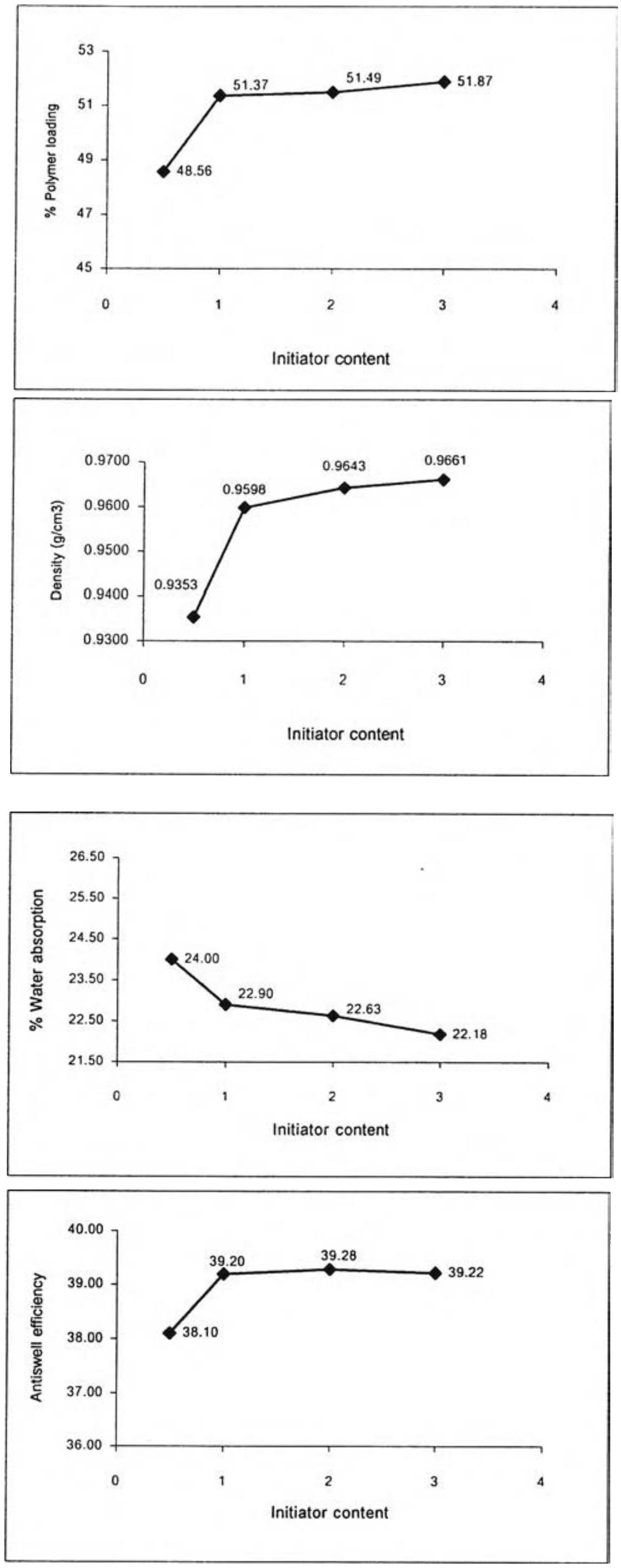


Figure 4.3 Physical properties of rubber wood-2-HPA composites prepared from various initiator contents

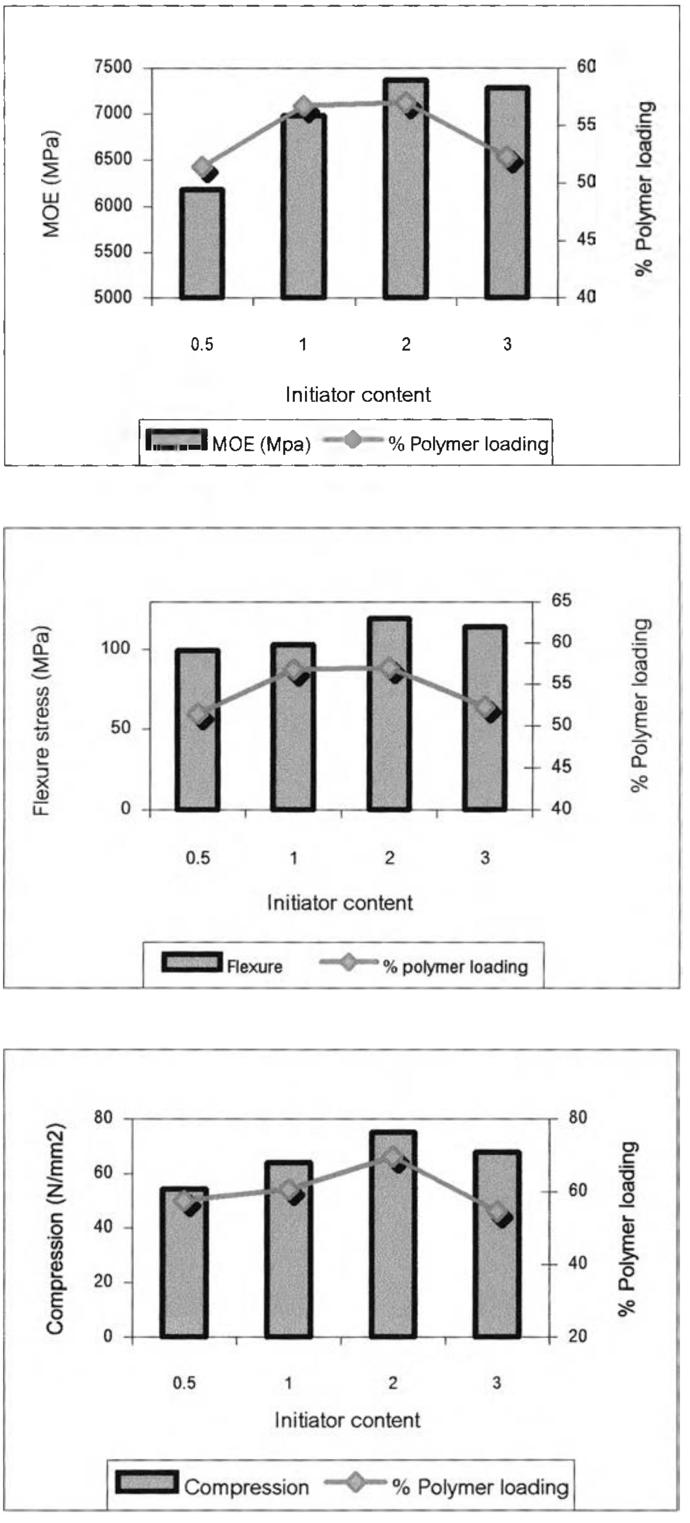


Figure 4.4 Mechanical properties of rubber wood-2-HPA composites prepared from various initiator contents

The physical properties of impregnated sample with various initiator contents of 2-HPA showed that polymer loading was increased with increasing initiator contents. They were not significantly difference at 1-3 phr initiator, resulting in the same values of density in such initiator contents.

The water absorption was decreased with increasing polymer loading, which could be explained that the increasing amount of polymer could fill up the lumen of wood, resulting in the reduction of hydroxyl groups of wood cell wall and prevented the absorption of moisture which consequence in improving ASE. Microstructure of the specimen was examined by scanning electron microscopy (SEM) and is shown in Figures 4.9-4.11.

From Figure 4.4, polymer loading was increased with the increasing initiator contents but it was decreased at 3 phr initiator. It could be explained that when the content of initiator increased, the rate of polymerization increased rapidly, resulting in the reduction of molecular weight and oligomer was obtained. In polymerization process, samples were curing in the oven at elevated temperature. It was possible that the oligomer was evaporated in that process. So polymer loading was decreased at 3 phr initiator. However, they were not significantly difference at 1-3 phr initiator.

Mechanical properties such as modulus of elasticity (MOE), flexure stress and compression parallel to grain of samples showed in the same trend with polymer loading. Samples impregnated with 2 phr initiator gave the highest values. However, they were not significantly different at 1 phr initiator. Thus, 2 phr initiator was enough to prepare rubber wood-2-HPA composites.

Table 4.5 Properties of rubber wood-2-BA composites prepared from various initiator contents

Physical properties	Initiator content (phr.)			
	0.5	1	2	3
Polymer loading (%)	33.58	37.09	44.40	45.38
Density (g/cm^3)	0.8043	0.8098	0.8531	0.8637
Water absorption (%)	26.24	24.20	21.65	21.17
Antiswell efficiency	29.24	30.58	33.55	34.48

Mechanical Properties	Initiator content (phr.)			
	0.5	1	2	3
Polymer loading (%)	37.39	40.40	42.62	46.02
MOE (MPa)	6640	7265	7013	6028
Flexure stress (MPa)	108.1	112.6	117.6	96.15

Polymer loading (%)	46.67	38.61	49.42	49.77
Compression (N/mm^2)	61.58	61.67	65.51	62.30

- Average data from 7 specimens for each treatment. (2 replicates)

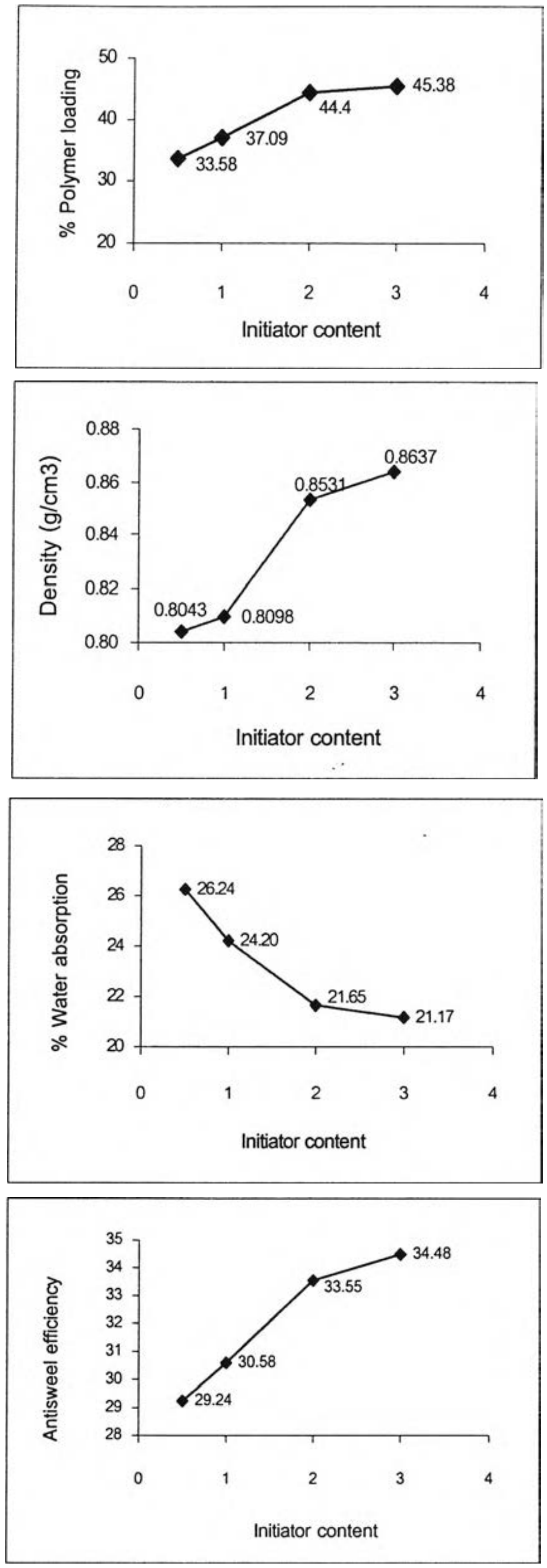
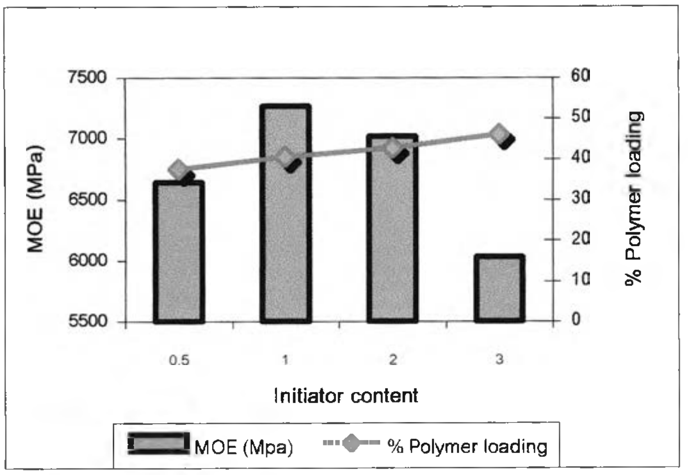
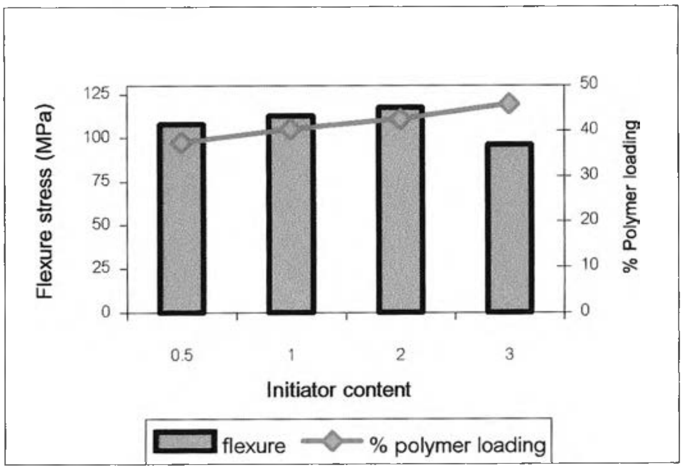


Figure 4.5 Physical properties of rubber wood-BA composites prepared from various initiator contents





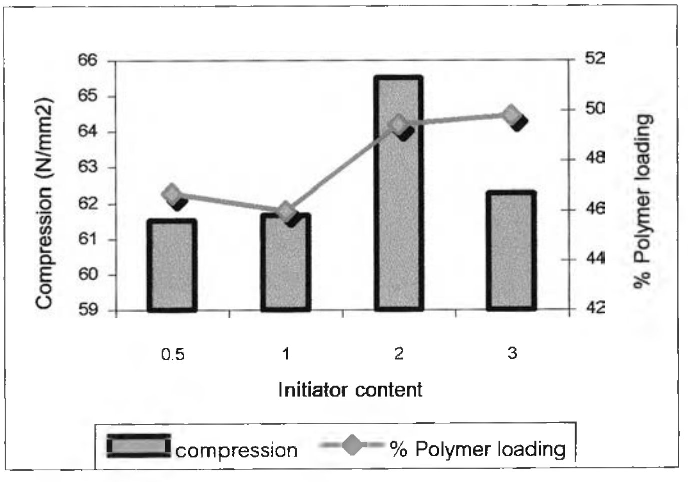


Figure 4.6 Mechanical properties of rubber wood-BA composites prepared from various initiator contents

Physical properties of impregnated samples with BA showed the same trend with 2-HPA that the polymer loading was increased with increasing initiator contents. The highest polymer loading obtained when samples were impregnated with 3 phr initiator. So they gave higher density and antiswell efficiency too. However, they were not significantly difference at 2-3 phr initiator.

From Figure 4.6, although, polymer loading was increased with increasing initiator contents, mechanical properties were not continuously improved. It could be explained by rate of polymerization that short chain molecules were obtained. Impregnating with 1-2 phr initiator gave higher MOE and flexure stress values than 0.5 and 3 phr initiator. The impregnated samples with 2 phr initiator gave the highest values of compression parallel to grain. Thus, 2 phr initiator was the optimum values to use in preparation of rubber wood-BA composites.

Table 4.6 Properties of rubber wood-2-EHA composites prepared from various initiator contents

Physical properties	Initiator content (phr.)			
	0.5	1	2	3
Polymer loading (%)	42.07	44.08	44.42	47.75
Density (g/cm^3)	0.9335	0.9464	0.9691	0.9725
Water absorption (%)	32.50	30.05	29.77	27.61
Antiswell efficiency	39.76	40.70	40.86	41.52

Mechanical Properties	Initiator content (phr.)			
	0.5	1	2	3
Polymer loading (%)	50.04	53.14	56.01	50.87
MOE (MPa)	7715	8412	8674	7709
Flexure stress (MPa)	117.4	130.3	122.8	111.2

Polymer loading (%)	47.98	55.28	55.89	50.05
Compression (N/mm^2)	53.03	63.32	55.12	55.90

- Average data from 7 specimens for each treatment. (3 replicates)

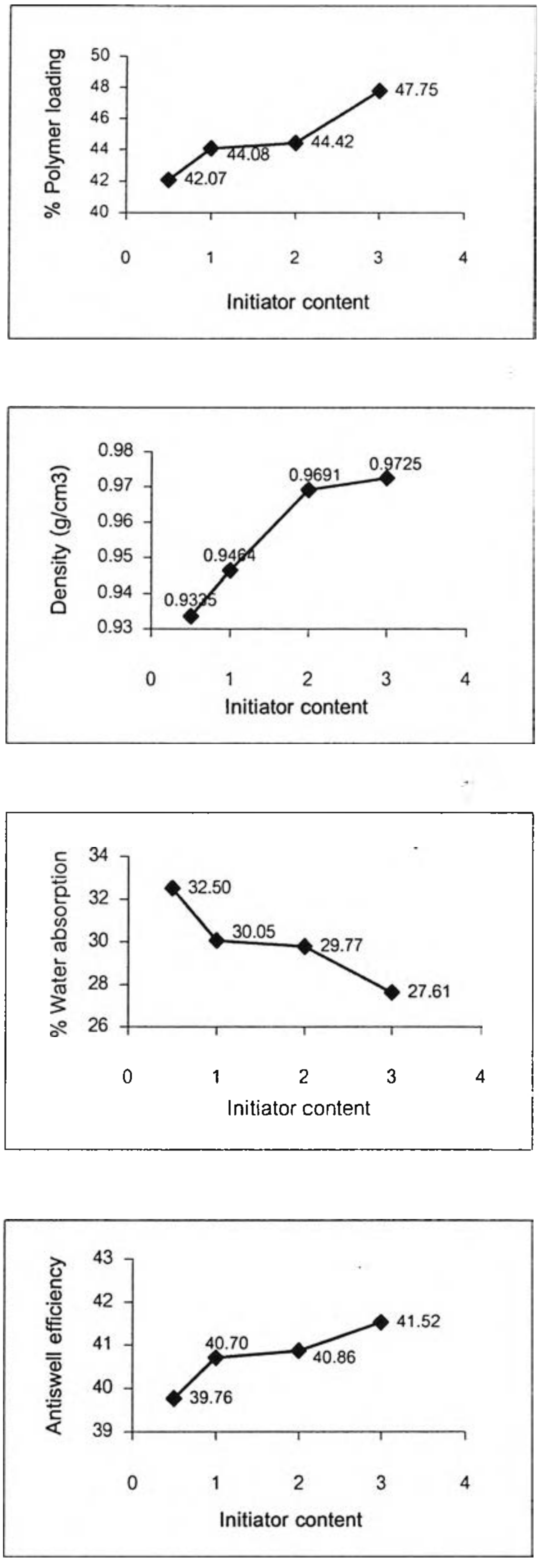


Figure 4.7 Physical properties of rubber wood-2-EHA composites prepared from various initiator contents

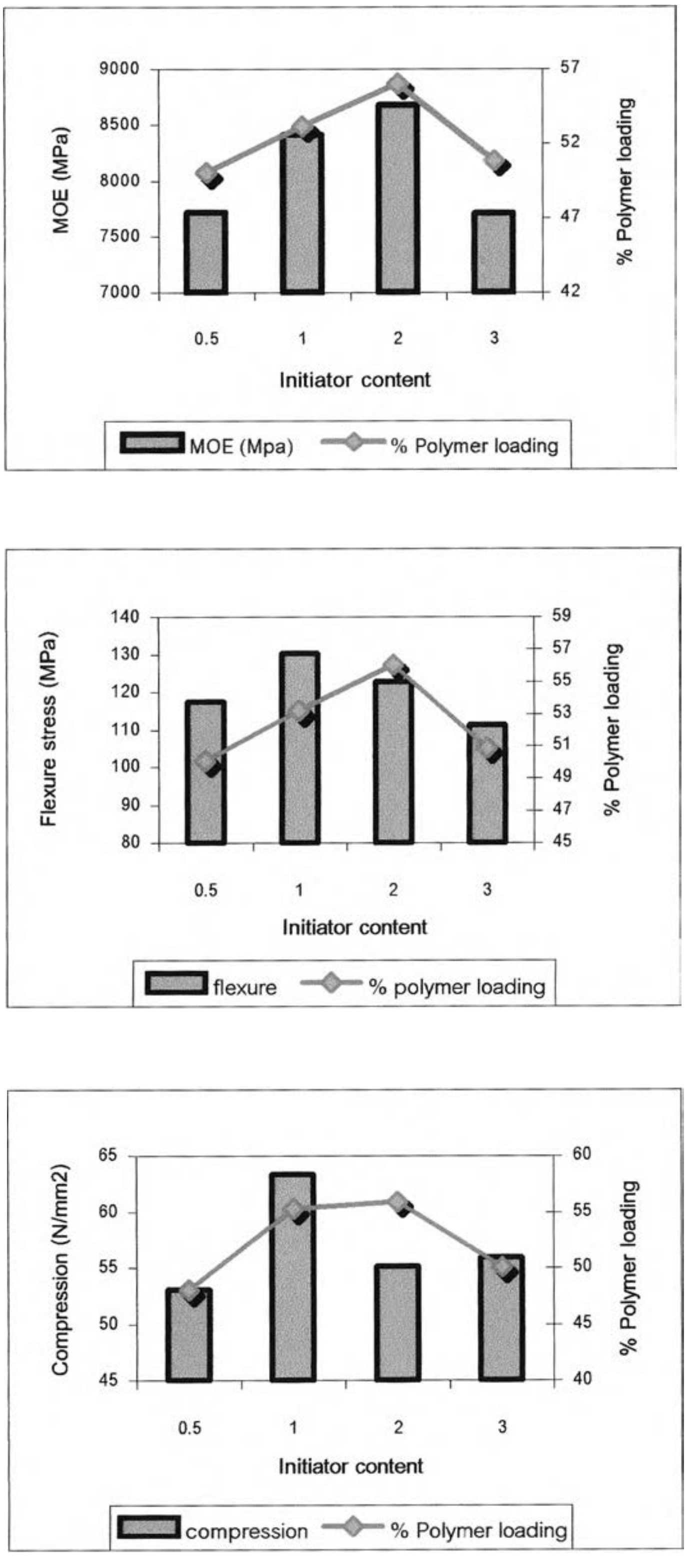


Figure 4.8 Mechanical properties of rubber wood-2-EHA composites prepared from various initiator contents

Figures 4.7-4.8 showed the physical and mechanical properties of rubber wood-2-EHA composites from various initiator contents. The results have the same trend as rubber wood-2-HPA and BA composites. They showed higher MOE and flexure stress at 1 and 2 phr initiator, respectively but they were not significantly difference between 1-2 phr initiator. At 1 phr initiator, they gave the highest values of compression parallel to grain.

These experimental results showed that samples impregnated with 1 phr initiator gave superior mechanical properties.

From Table 4.4-4.6, the superior physical and mechanical properties of rubber wood-polyacrylate composites were compared and are shown in Table 4.7.

Table 4.7 The properties of rubber wood-polyacrylate composites

Properties	2-HPA	BA	2-EHA
Polymer loading (%)	57.00	42.62	53.14
Density (g/cm^3)	0.9643	0.8531	0.9464
Water absorption (%)	22.63	21.65	30.05
Antiswell efficiency	39.28	33.55	40.70
MOE (MPa)	7364	7013	8412
Flexure stress (MPa)	119.2	117.6	130.3
Compression (N/mm^2)	75.02	65.51	63.32

From the properties values, it was found that 2-HPA has the best ability to penetrate into wood cells because the size of 2-HPA is small and hydroxyl group in its structure could form hydrogen bond with cellulose in wood cells. Although, 2-EHA is larger than BA, 2-EHA has polymer loading values higher than polymer loading of BA. BA has lower boiling point so polymer loading could be lost while curing in polymerization process. Consequently, density of rubber wood-2-HPA composites is more than others.

Antiswell efficiency of rubber wood-2-EHA composites is better than others whereas sample of BA showed the lowest antiswell efficiency.

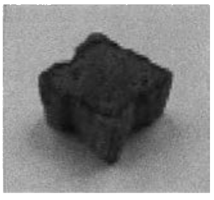
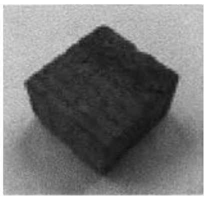
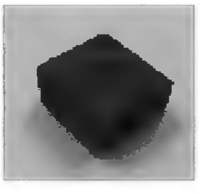
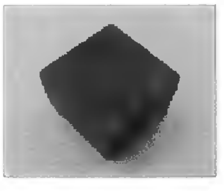
From the mechanical properties, sample of 2-EHA composites showed the best values of MOE and flexure stress at 8412 and 130.3 MPA, respectively, whereas sample of 2-HPA and BA composites showed non significantly difference values of MOE and flexure stress. It could be explained that molecule of 2-EHA is a long six carbons chain with acrylate. Flexibility of acrylate is depends on the length of alkyl group in molecular structure. As mentioned above, samples of 2-EHA composites gave more MOE and flexure stress. While molecule of 2-EHA and BA which has 2 and 3 carbons chain, respectively, gave nearly the same values of MOE and flexure stress.

Rubber wood-2-HPA composites showed the highest values of compression parallel to grain at 75.02 N/mm^2 whereas sample of BA and 2-EHA composites showed non significantly difference values of compression parallel to grain. It was possible that hydroxyl group in structure of 2-HPA could improved the compression parallel to grain.

4.5 Evaluation of WPC specimens for termite resistance

Although, rubber wood has physical and mechanical properties enough to use for products of various kinds, it can be easily attacked by wood-boring insects, such as subteranean termite or other fungi. The WPC making is an alternative way to protect rubber wood from deterioration. In this research, untreated rubber wood, Makah-mong, Red wood and treated rubber wood were tested under the same condition and the results are shown in Table 4.8.

Table 4.8 The result of rating of termite attack

Types of wood	Rating of termite attack	Types of wood	Rating of termite attack
 **Untreated wood**	**3**	 **Treated wood 2-HPA**	**10**
 Makah-mong	**10**	 **Treated wood BA**	**10**
 **Red wood**	**10**	 **Treated wood 2-EHA**	**10**

As the results of Table 4.8, it was found that termites preferred to attack untreadted rubber wood more than others. The other woods such as treated rubber woods, Makah-mong and Red wood were not damaged by termites under the tested condition. Thus, the rubber wood impregnated with acrylates were more resistant to termite attack.

4.6 Scanning Electron Microscopy (SEM) of WPC

The microstructure of rubber wood polymer composite was examined by scanning electron microscopy (SEM) of transverse sections of the specimens. The microstructure of untreated rubber wood cells are shown in Figure 4.9. The microstructure of impregnated rubber wood cells are shown in Figure 4.10 and Figure 4.11.

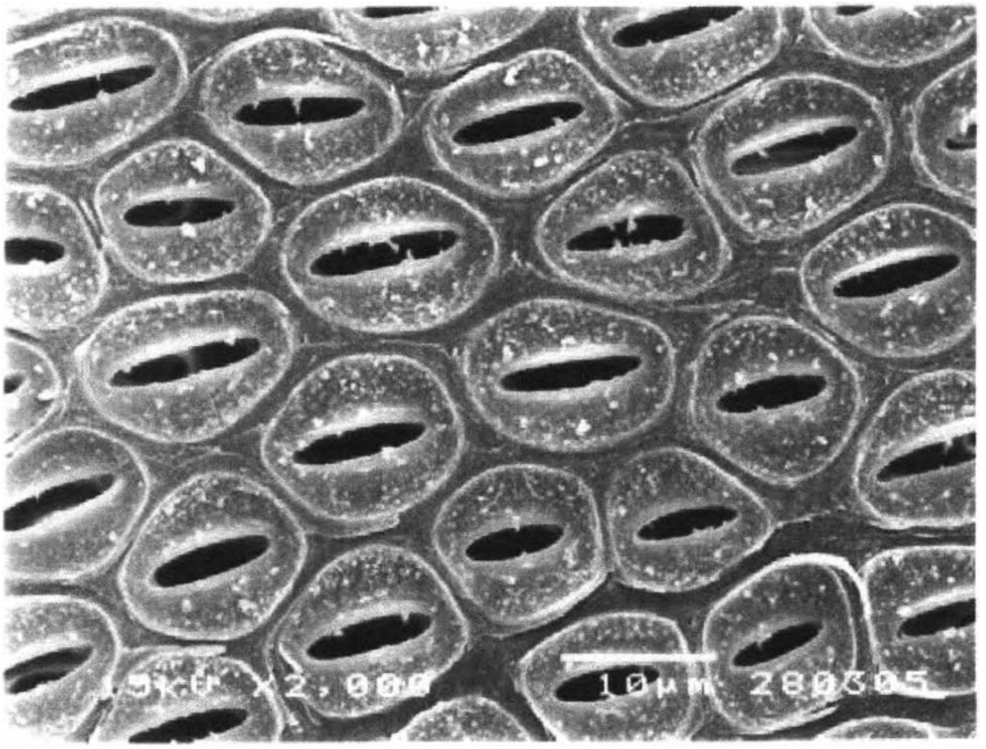


Figure 4.9 Scanning electron microscopy of transverse section of empty rubber wood cells (2,000X)

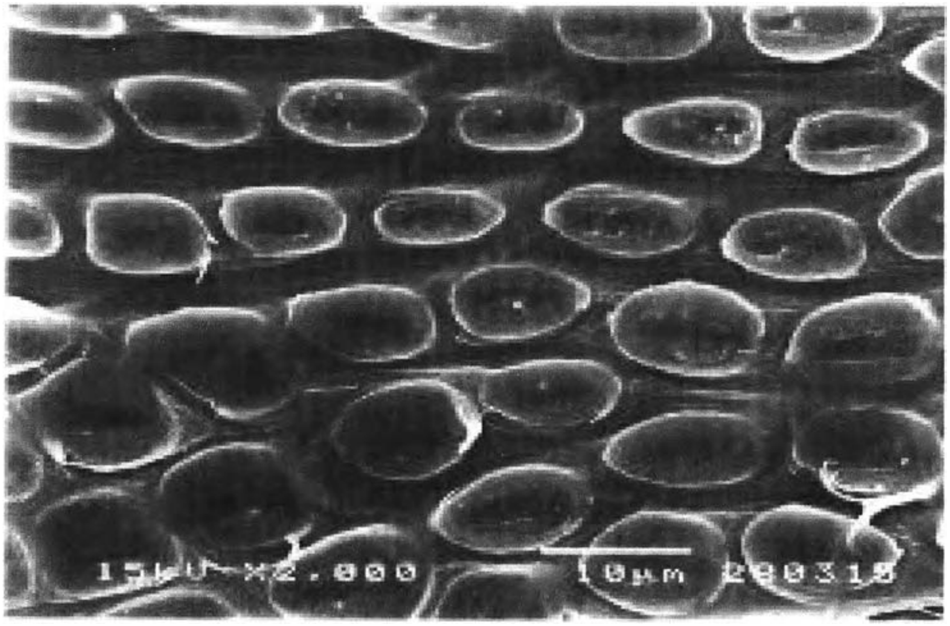


Figure 4.10 Scanning electron microscopy of transverse section of polymer filled cells (2,000X)

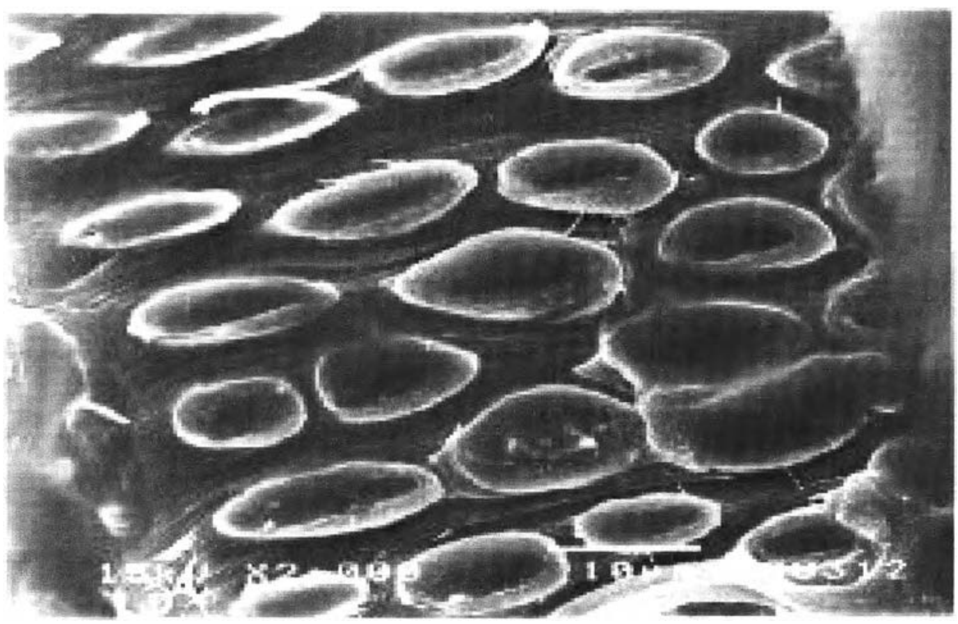


Figure 4.11 Scanning electron microscopy of transverse section of polymer filled cells (2,000X)

From Figure 4.9, the microstructure of untreated rubber wood cells revealed the empty void spaces in wood cells. Figures 4.10 and 4.11 indicated that the void spaces of wood cells were filled with polymer, which was important consequence on the improvement of physical and mechanical properties of natural rubber wood.

4.7 Application of rubber wood-polymer composites

In this study, rubber wood-polymer composites had better physical and mechanical properties as shown in Table 4.10.

Table 4.9 Comparison of the properties of rubber wood-polymer composites with other woods

Types of wood	Properties		
	MOE (MPa)	Flexure stress (MPa)	Compression (N/mm^2)
Untreated rubber wood	6219	93	42.15
Rubber wood-2-HPA composites	7364	119	75.02
Rubber wood-BA composites	7013	118	65.51
Rubber wood-2-EHA composites	8412	130	63.32
Durian wood-polyester resin composites [20]	11790	180	75.90
Rubber wood-epoxy resin composites [21]	9271	154	72.00
Rubber wood-poly(styrene-*co*-BA) composites [22]	9780	150	77.44
Rubber wood-poly(styrene-*co*-AM) composites [22]	8016	122	70.73
Rubber wood-poly(MMA-*co*-2-EHA) composites [23]	8699	130	77.36
Rubber wood-poly(MMA-*co*-AM) composites [23]	7992	125	70.99
Red wood	5790	82	82.30
Teak wood	6398	98	86.30

From Table 4.9, rubber wood impregnation with 2-HPA, BA and 2-EHA could improve the mechanical properties of natural rubber wood. The 2-HPA gave better compression whereas the 2-EHA gave more MOE and flexure stress.

Comparing with durian wood-polyester resin composites and rubber wood-epoxy resin composites, they gave higher MOE and flexure stress than those of 2-HPA, BA and 2-EHA-rubber wood composites. There was only 2-HPA that gave high compression enough. Comparing with rubber wood-copolymer of styrene and MMA composites, rubber wood-polyacrylate composites gave lower properites. Rubber wood-poly(styrene-*co*-BA) composites could improve properties of natural rubber wood and gave the best results. Rubber wood-poly(MMA-*co*-2-EHA) composites gave MOE and flexure stress similar to those of rubber wood-2-EHA composites.

However, MOE and flexure stress of rubber wood-polyacrylate composites were higher than those of red wood and teak wood. Therefore, treated rubber wood could have good potential to be applied in some applications that use teak wood or red wood such as furniture, household item, etc.