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**MECHANICAL PROPERTY IMPROVEMENT OF
DURIANWOOD WITH POLYESTER RESIN**

Miss Busarin Kasamchainanta



**A Thesis Submitted in Partial Fulfillment of the Requirements
For the Degree of Master of Science in Petrochemistry and Polymer Science
Program of Petrochemistry and Polymer Science**

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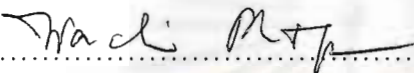
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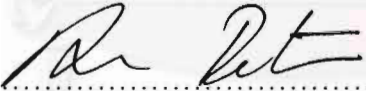
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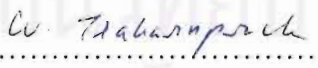
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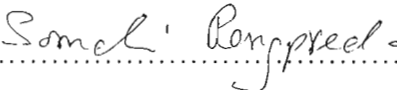
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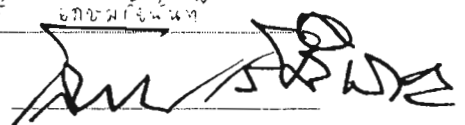
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ลายมือชื่ออาจารย์ที่ปรึกษาร่วม

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BUSARIN KASAMCHAINANTA : MECHANICAL PROPERTY
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This research involves the preparation of durianwood-polyester resins composites by impregnation under reduced pressure. The effects of diluent content, initiator types, initiator content that related to viscosity and cure time of prepolymer mixtures were studied. Impregnation parameters such as the evacuating time and the soaking time were varied to several conditions in the preparation process. Physical and mechanical properties of impregnated samples were compared with natural durianwood.

Results of this study showed that 90% by wt. of polyester resins, 10% by wt. of styrene monomer and 1 phr. benzoylperoxide were suitable for impregnating prepolymer mixture into durian matrix. The optimum preparation parameters were 1 hour evacuating time and 3 hours soaking time. Impregnated samples obtained from the optimum conditions gave significant lower water absorption, higher antishrink efficiency than natural durianwood, higher modulus of elasticity, higher flexural stress, higher compression parallel to grain and higher density than natural durianwood.

สาขาวิชา ปิโตรเคมีและวิทยาศาสตร์พอลิเมอร์

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ปีการศึกษา 2542

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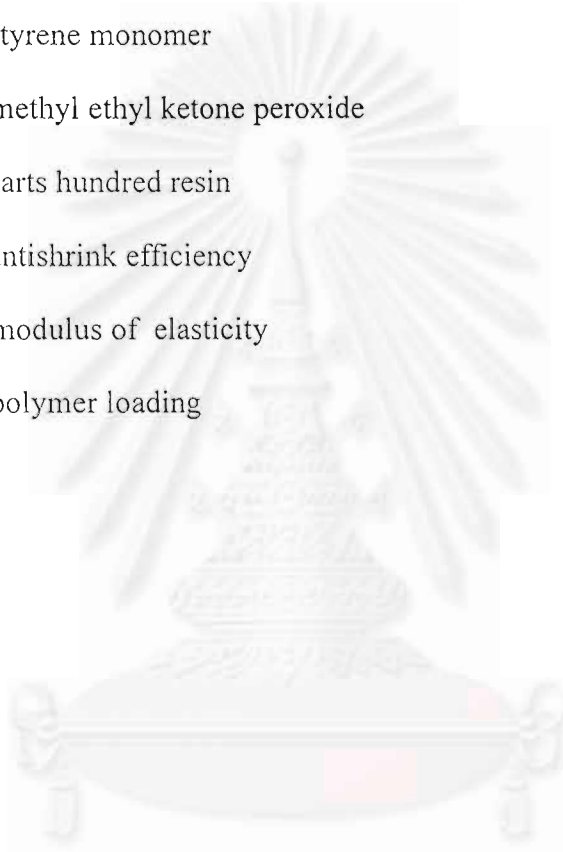
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LIST OF ABBREVIATION

WPC	-	wood-polymer composite
UPR	-	unsaturated polyester resin
SM	-	styrene monomer
MEKPO	-	methyl ethyl ketone peroxide
phr.	-	parts hundred resin
ASE	-	antishrink efficiency
MOE	-	modulus of elasticity
PL.	-	polymer loading



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CHAPTER 1



INTRODUCTION

Initially, scientific inquisitiveness led scientists to do research on the improvement of wood products. From ancient times, people have been trying to improve wood timber by polishing it with wax and oils of different kinds and various herbal materials to protect wooden boats, ships, wheels of carts, etc. Efforts of wood improvement have also been made to prevent erosion, salinity, and attack by microbes, insects, and moisture absorption.

In a real sense, the modification of various physical and mechanical properties of wood and its products by chemical treatment started in the 1930s [1]. But, the momentum gained after World War II when there was a real break-through of scientific activities in almost all fields. To catch up with modernization, the world forest reserve has been indiscriminately used. As a result, good quality timber reserves started to shrink rapidly in many countries and led people to use low quality wood as a substitute for high quality timber. Moreover, there are some parts of machines where the use of wood is essentially required, i.e., submarine propeller shafts. There are many countries in the world where there is an acute dearth of high quality timber and low grade wood is being used as a substitute. As a result, quality

products with the desired properties are seldom available. All these accumulated factors led to development of wood- polymer composites.

According to this research, the durianwood from the southern part of Thailand was used. This durianwood is classified in the *Durio graveolens* Becc. that widely grow in Thailand, Malaysia and Indonesia[2]. In general, the durian is considered to be a favorable fruit, despite the unfavorable taste. Therefore, agriculturists are not interested in growing it. This type of durian tree generally has a straight trunk and high, which are useful qualities of the durianwood. Nowadays, durianwood is scarcely used. Most of the wood from the felled trees is used as fuel because of certain properties such as low durability and resistance to insects, which are still important problems when this wood is applied. Therefore, the purpose of this research is to add economic value to durianwood by improving its physical and mechanical properties.

1.1 Objective of the research work

1. To study the durianwood-unsaturated polyester resin composites prepared by impregnation under reduced pressure.
2. To study physical and mechanical properties of durianwood-unsaturated polyester resin composites obtained under various conditions.

1.2 Scopes of the research work

In this research work, the wood-polymer composites were prepared from unsaturated polyester resin prepolymer mixtures and durianwood by impregnation under reduced pressure. Suitable prepolymer mixture and various impregnation

conditions such as diluent content, initiator type and content, soaking time, evacuating time and evacuating pressure were investigated. The physical and mechanical properties of the specimens such as polymer loading, water absorption, antishrink efficiency, density, hardness, modulus of elasticity, flexure stress, compression parallel to grain, resistance to termite and SEM of microstructure figure were studied.



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CHAPTER 2

THEORY AND LITERATURE REVIEW

Wood is a preferred building and engineering material because it is economical, low in processing energy, renewable, strong and aesthetically pleasing. It has, however, several disadvantageous properties such as biodegradability, changing dimensions with varying moisture contents, and some unsuitable physical and mechanical properties. Therefore, wood-polymer composites is an option to solve these problems.

2.1 Definition of wood-polymer composites

Wood-polymer composite (WPC) [3] is a wood impregnated with polymers in order to strengthen the properties of the natural wood. In a broad sense, WPC includes the composite (Compreg or Impreg), that is made by impregnating wood with phenol-, a urea-, or a melamine-formaldehyde prepolymer and curing the prepolymer to a solid for improving dimensional stability and its properties. WPC also includes a high-wood filler content resin that is made by mixing a thermoplastic resin (polypropylene resin, poly(vinyl chloride) resin, etc.) with fine wood-filler and pelletizing them for molding of the resin.

However, in the narrow sense, WPC is a composite, made by impregnating wood with a polymerizable monomer, mainly vinyl-monomer or prepolymer, and polymerizing them to a solid. In this section, the wood-polymer composite is defined in the narrow sense.

2.2 Formation and structure of wood [2]

Within living trees, wood is produced to perform the roles of support, conduction and storage. The support role enables the tree stem to remain erect despite the height to which a tree grows. Because of this height, wood also must perform the role of conduction, that is, transport water from the ground to the upper parts of the tree. Finally, food is stored in certain parts of the wood until required by the living tree. The wood cells which perform the role of conduction and/ or support make up 60 to 90 percent of the wood volume. Within the living tree these cells are dead, that is, the cytoplasm is absent leaving a hollow cell with rigid walls. The only living cells within the wood portion of a tree are the food-storing cells. The close relationship between form and function simplifies the study of wood anatomy if the role of the cells in the living tree is kept constantly in view.

2.2.1 Anatomy of wood

The end view of a log (Figure 2.1) exposes the wood and bark portion of a tree trunk. Each year a growing center located between the wood and bark inserts a new layer of wood adjacent to the existing wood. In addition, new bark is deposited

next to the pre-existing bark. Wood occupies the largest volume of a tree stem because more wood cells are produced than bark cells and also because the wood cells are retained and thus accumulate while the outermost bark cells are continually discarded.

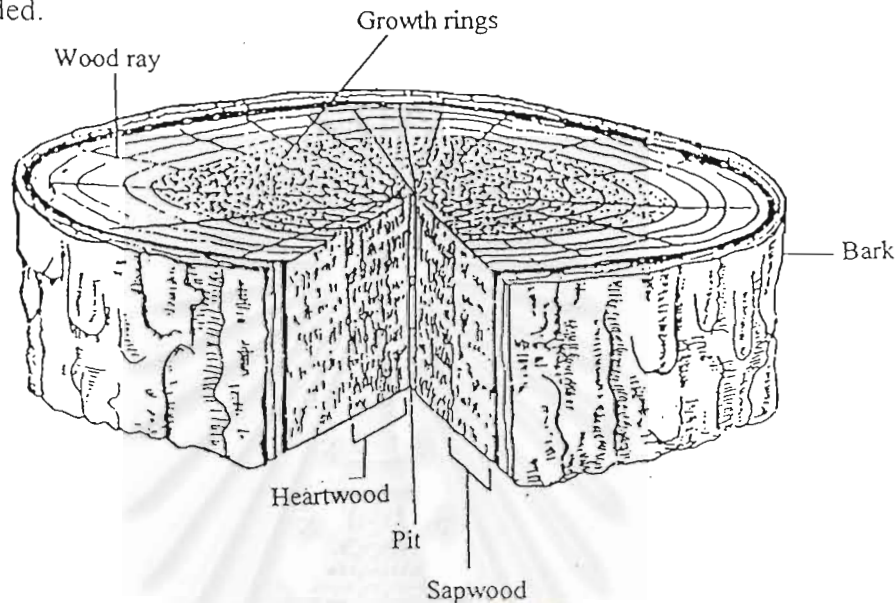


Figure 2.1 End view of a log showing both the wood and bark.

The central wood portion of the log depicted in Figure 2.1 is considerably darker in color than the part adjacent to the bark. The dark-colored wood is termed heartwood and the light-colored wood is termed sapwood. A new wood, that is sapwood, is formed to outside of the tree stem, additional interior sapwood adjacent to heartwood zone is converted to heartwood. It should be apparent that the vast majority of cells which constitute the wood portion of a living tree, are dead. The sapwood zone contains the only living cells found in mature wood and they constitute, depending upon species, from 10 to 40 percent of sapwood volume. As heartwood is formed these living, food-storage cells die, thus the heartwood contains only dead cells.

Growth rings, or annual increments, are detectable due to differences in the wood produced early and late in the growing season. The wood produced early, called earlywood or springwood, is considerably lighter in color than the wood termed latewood or summerwood which is produced late in the growing season.

Wood rays are found in all species of wood and consist of ribbon-like aggregation of food-storing cells extending in the transverse direction from the bark toward the center of the tree. In the cross-sectional view, rays take the form of lines of varying width running at right angles to the growth rings.

Trees are classified into two major groups termed softwoods (gymnosperms) and hardwoods (angiosperms). The major difference with regard to wood anatomy is the presence of vessels in hardwoods. Vessels are structures composed of cells created exclusively for the conduction of water. Softwoods lack vessels but have cells termed longitudinal tracheids which perform a dual role of conduction and support.

The terms softwood and hardwood are not to be taken as a measure of hardness since some hardwoods are softer than many softwoods. For the commercially important domestic woods, the average specific gravity for softwoods is 0.41 and hardwoods average 0.50.

2.2.1.1 Softwoods [5]

The softwoods (Figure 2.2) are comparatively homogeneous, consisting essentially of two main elements or cell forms: tracheids, concerned in the living tree with the dual function of sap conduction and mechanical support, and rays, which

serve chiefly for storage and horizontal conduction of food materials. In certain softwoods, the wood is characterized by the presence of vertical and radial intercellular canals or resin duct. Wood parenchyma cells, other than the epithelial parenchyma, which surrounds and limits the resin ducts, also occur in some softwood species but are sparsely developed.

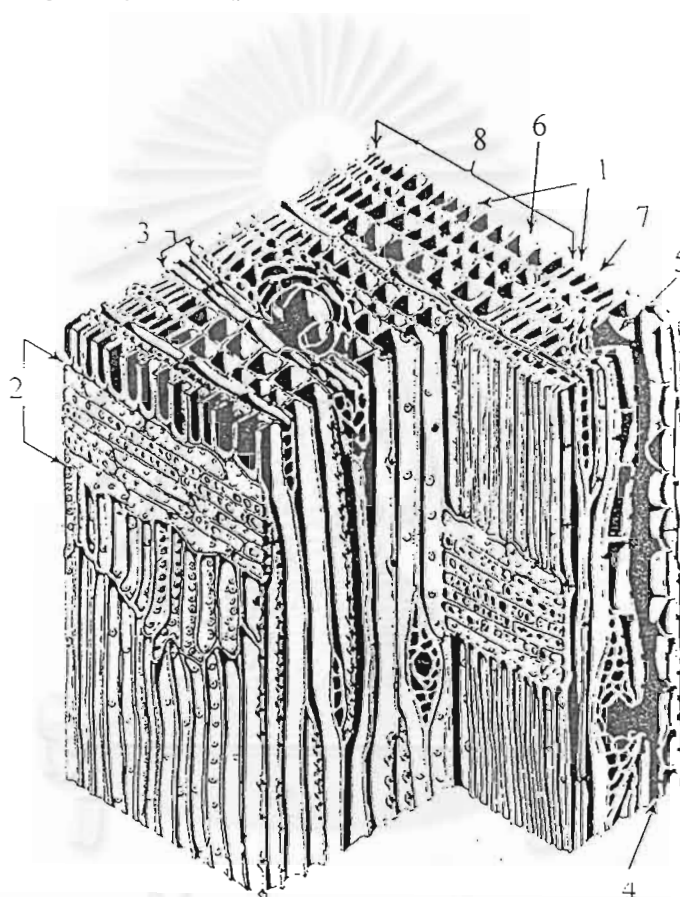


Figure 2.2 Magnified three-dimensional diagrammatic sketch of softwood. :

- (1) tracheid, (2) wood ray, (3) fusiform wood ray. (4) vertical resin duct.
 (5) horizontal resin duct, (6) springwood, (7) summerwood, (8) annual
 -ring.

2.2.1.2 Hardwoods

The hardwoods [Figure 2.3] are heterogeneous in their structure, having a greater complexity of cell forms, associated with a more marked division of labor in the living tree, than is the case in the softwoods. Ascent of sap in the stem is facilitated by tubelike structures known as vessels; mechanical support is provided by fibers; food storage and conduction are functions of the rays and also of the wood parenchyma cells, which are quite well developed in some species.

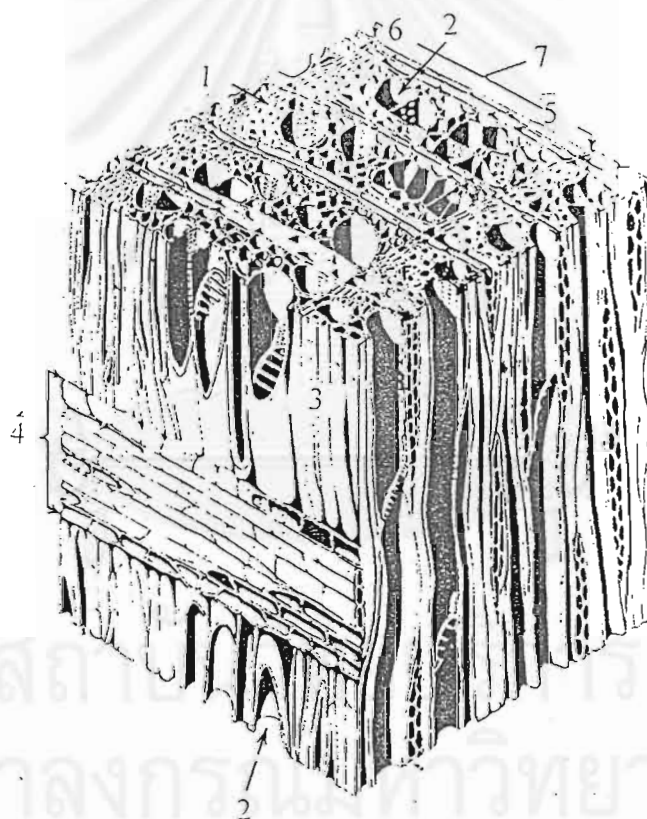


Figure 2.3 Magnified three dimensional diagrammatic sketch of a hardwood:

- (1) fibers, (2) vessels or pores, (3) pits, (4) wood rays, (5) springwood, (6) summerwood, (7) annual ring, (8) wood parenchyma

2.3 Flow Paths in Wood[6]

Since wood is cellular in nature, flow of fluids from cell to cell must either be through cell walls or through the pit pairs. Thus, the pit membrane is the structural component which essentially controls permeability.

2.3.1 Flow paths in softwoods

In longitudinal and tangential directions, flow occurs primarily through tracheid lumens and bordered pit pairs in series. Some softwoods possess longitudinal resin canals and parenchyma cells which can function as avenues for flow. However, because of the relatively small number and possible occlusion with resins, the amount of flow in these elements is minor in most cases.

Rays appear to offer a major flow path in the radial direction. When present, the ray tracheids are generally more effective in conduction than the ray parenchyma cells, but there has been at least one case where the reverse is true. Since every tracheid makes contact with at least one ray, these contact areas offer flow paths into longitudinal tracheids through bordered pits.

2.3.2 Flow paths in hard woods

Longitudinal liquid movement in hardwood is primarily through the vessels. The ends of the vessel cells are perforated and, unless the vessels are blocked by tyloses, they provide continuous flow paths. Once the fluid is in the vessels, flow can occur laterally through bordered and half-bordered pit pairs into the

adjoining elements. Because of the complex structure, the relative effectiveness of libriform fibers, fiber tracheids, vasicentric tracheids, and longitudinal parenchyma as flow paths is not known. However, these elements undoubtedly contribute at least in a minor way to the total flow pattern.

2.4 Plastic and its relation to wood [1]

To overcome these unfavorable properties of wood, people have attempted various kinds of physical and chemical treatments, such as steaming, compacting, impregnation with monomer and chemical transformation to changes or by chemical treatments of the low grade wood transform it to work as a substitute for the higher grades.

Fortunately, this improvement has been facilitated by the advent of a plastic that has many properties very similar to wood. A resinous plastic can be like a characteristic cellulose constituent of wood; it is strong and resistant below the softening point and a thick, viscous fluid above it. Structurally like cellulose, crystalline regions and amorphous parts can be easily distinguished. Bulk density, strength, and other physical properties of wood and plastic are very much related to each other.

In spite of some similarities in their properties, plastic has, unlike wood, high resistance to water absorbability and is hydrophobic. It is also durable in various weather conditions and resistant to pest attack. Thus, the combination of wood and

plastic makes a very promising product for industrial application. By combining plastic with wood through chemical treatment, radial and tangential strengths can be enhanced to the same degree as that of its longitudinal strength, which is the real unilateral strength of the wood. The combination also makes product more resistant to abrasion, biological attack, and weather conditions.

2.5 Unsaturated polyester resin (UPR) [7,8,9]

An unsaturated polyester resin usually contains a polymerizable vinyl monomer and unsaturated polyester, which is prepared from glycol and dibasic acids. The linear chain unsaturated polyester is dissolved in vinyl monomer, usually styrene, and the resulting resin is called an unsaturated polyester resin. This resin can be cured by use of catalysis to yield hard insoluble thermoset polyester.

2.5.1 Preparation of Unsaturated polyester

Unsaturated polyesters are usually prepared from a polycondensation reaction at elevated temperature between glycols and dibasic acids or anhydrides as shown in Figure 2.4.

Depending on the type of glycols and acids, the unsaturated polyester is a linear polymer with a molecular weight ranging between 700-20000. They are prepared in large reactors with overhead equipment designed to reduce the loss of volatile components. The acid number or a combination of acid number and viscosity

of the polyester determines the end point of polyesterification reaction. After unsaturated polyester has been prepared, it must be inhibited and diluted with vinyl monomer.

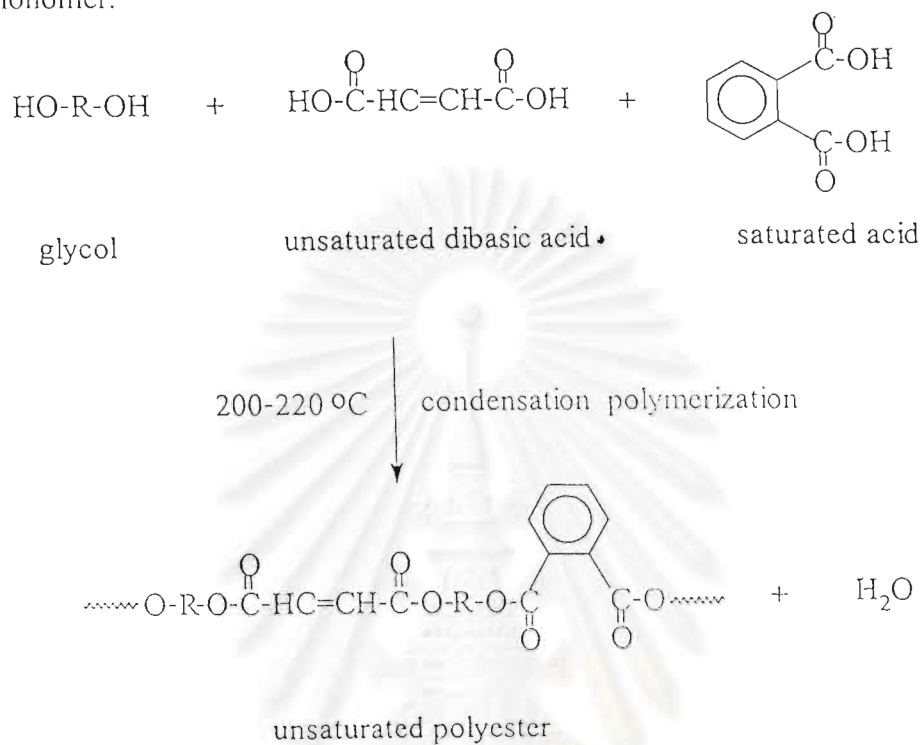


Figure 2.4 Preparation of unsaturated polyesters

2.5.2 Curing

Methyl ethyl ketone peroxide is most widely used of the low-temperature peroxide (20-60 °C). Benzoyl peroxide is the most popular of the medium temperature peroxides (60-120° C). Tertiary butyl perbenzoate and dicumyl peroxide are widely used in molding systems that require temperature in range of 120-150°C.

An accelerator is sometimes used to react with the peroxide to generate free radicals at a lower temperature. Metals and tertiary amine are the accelerators that are widely used.

The curing of unsaturated polyester resin is a free radical polymerization is shown in Figure 2.5

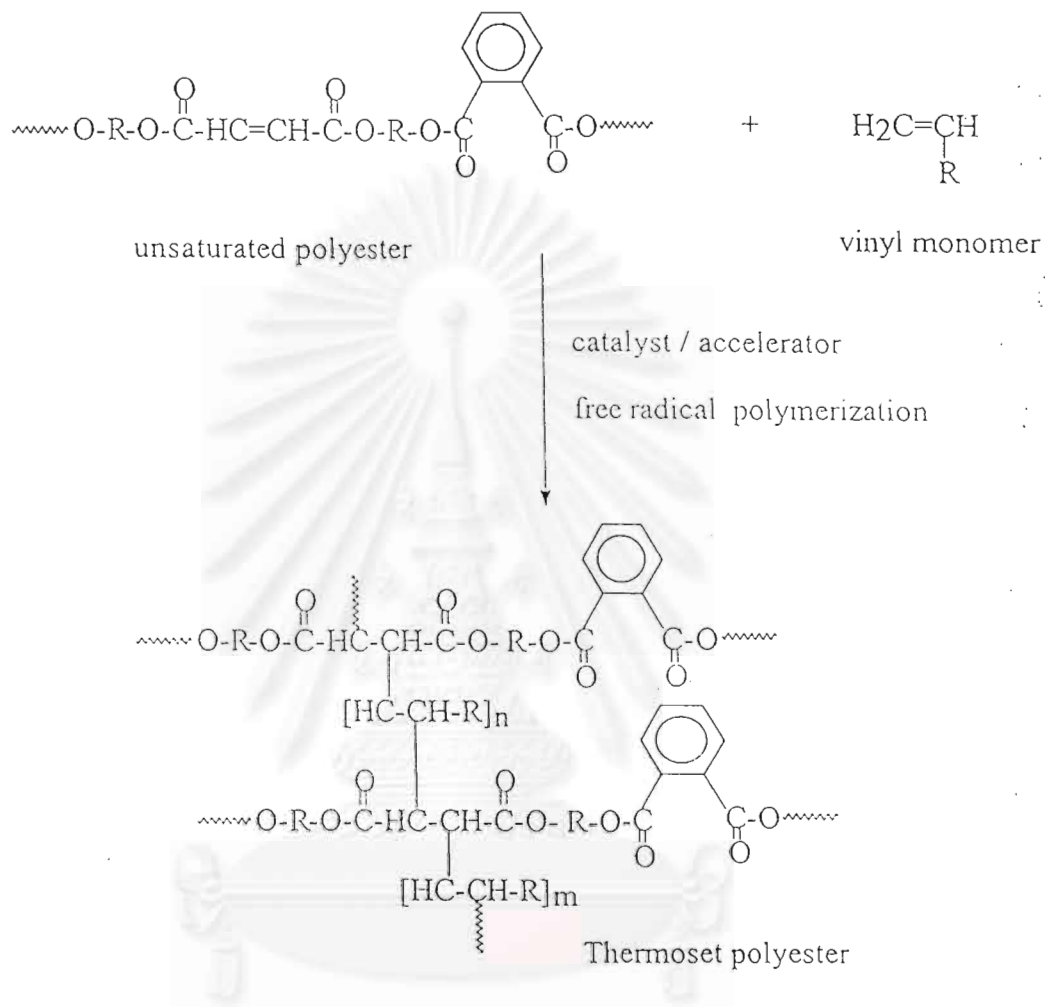


Figure 2.5 Preparation of a thermoset polyester

2.6 Impregnation Process [10]

In process the impregnation of wood is carried out by first evacuating the air from the wood vessels and cell lumens. Any type of mechanical vacuum pump is adequate that can reduce the pressure in the apparatus to 133 pa (1 mm Hg) or less.

The air in the cellular structure of most woods is removed as fast as the pressure in the evacuation vessel is reduced. After that the vacuum pump is disconnected from the system. The catalyzed prepolymer containing cross-linking agents and occasionally dyes, is introduced into the evacuated chamber through a reservoir at atmospheric pressure. The wood must be weighted down so that it does not float on the prepolymer solution. In the radiation process no catalyst is required. After the wood is covered with the monomer solution, air is admitted at atmospheric pressure or dry nitrogen in the case of radiation process. The monomer solution begins to flow immediately into the evacuated wood structure to fill the void spaces. The soaking period, like the evacuation period, depends on the structure of the wood. After impregnation is completed, the wood-polymer composite is removed and placed in an oven or exposed to a cobalt-60 source for curing. The apparatus of impregnation is shown in Figure 2.6.

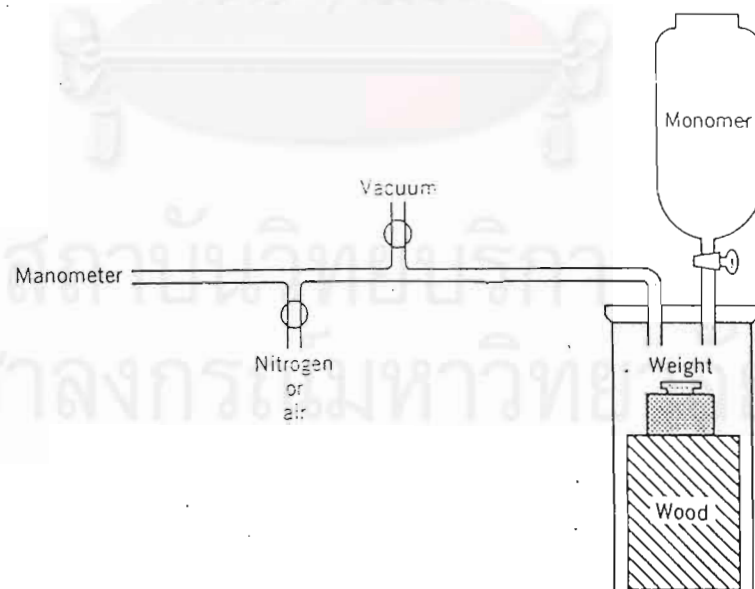


Figure 2.6 The apparatus of impregnation process

2.7 Properties of WPC [3]

WPC has changed and improved in many areas, compared with untreated wood. Its notable advantages are an increase in the static strength, surface hardness abrasion resistance, dimensional stability, fine-finishing, and attractive grain.

2.7.1 Mechanical properties

The most pronounced mechanical properties improved by WPC are compression strength and hardness. These properties are improved 4 to 5 times that of untreated samples, if attentive selection is made to the wood species and monomers. This is the reason that the first commercial use of WPC was flooring. The properties of WPC are improved 1.5 to 2 times for tension, bending, and impact strengths, compared to untreated wood.

2.7.2 Dimensional stability

The introduction of polymers generally reduces swelling and shrinking from water, and promotes dimensional stability. WPC especially, shows more resistance to water absorption because of the resistance of water vapor-diffusion from polymer in the cell lumen. Otherwise, antismelling efficiency (ASE) depends on the volume-effect after WPC treatment, i.e., bulking effect. The larger the volume of bulking is, the more WPC has dimensional stability. Regarding ASE of WPC with polymer loading, it shows the maximum value between from 30 to 70% of polymer loading.

2.7.3 Manufactured properties

WPC has a fine finishing surface from sanding or buffing without surface coating. Woodworking machines cannot be used well, metal- or plasticworking machines are better suited for WPC. If these machines are used for WPC, unexpectedly fine machining properties may appear. WPC can be glued after WPC treatment with special techniques, depending upon suitable adhesives and treating processes, such as sanding or ozonolysis on the surface of WPC.

2.7.4 Decay resistance

WPC shows an increase in decay resistance. The rate of weight loss of white rot and brown rot decreases accompanied by increase of polymer loading. The weatherability of WPC is improved fairly well in untreated wood, but is not good enough for long-term outdoor use. Higher weatherability can be expected by adding an ultraviolet-absorbent to monomer or a polyurethane resin coating on the surface of WPC.

2.8 Application of WPC

There are many potential applications for WPC material (Table 2.1). Commercial production of WPC began in the mid 1960s using the radiation process in the U.S. and in the early 1970s using the catalyst-heat process in Japan. Now there are many companies more than five in the U.S., more than six in Japan, that produce WPC products, mainly flooring. The former is the flooring for heavy duty walking-resistant to footwear, and the latter is mainly for light duty walking. If the cost of

goods installation, easy maintenance, and long-life of WPC flooring is considered, the total cost of WPC flooring becomes one of the least expensive. Because WPC parquet flooring in the U.S. is guaranteed for 20 years, its requirement for WPC flooring may be superior to other flooring materials. There are few reports searching the practical use of wooden flooring, in spite of frequent use in office buildings, airport terminals, and private houses.

Table 2.1 Some Commercially Produced WPC Goods

Item	Goods
Housing	Flooring
	Stairs
	Sundeck floors
Furniture	Desks
	Chairs
Sports and leisure	Golf clubs
	Billiard cues
	Bowling lanes
	Gunstocks
Stationery	Fourtain pen stocks
	Letter holders
	Stationery stones
Others	Buttons, Bowls, Vases.
	Railroad ties, Truck beds

2.8 Literature review

Rozman, H.D., Kumar, R.N., and Abusamah, A. [11] prepared wood-polymer composite by impregnating rubberwood with methyl methacrylate (MMA) and the combinations of MMA and diallyl phthalate (MMA/DAP). Polymerization was carried out by catalytic heat treatment. Impregnated samples showed significant improvements in compressive and impact strengths, hardness and dimensional stability over that of the untreated rubberwood.

Husain, M.M., Khan, M.A., Ali, K.M.I. and Mustafa, A.I. [12] studied the impregnation of methylmethacrylate into Simul, a fuel wood of Bangladesh under vacuum and under normal temperature and pressure conditions in order to compare the mode of impregnation and its effect on various characteristic parameters of wood plastic composites. Impregnation of bulk monomer was very high under vacuum compared to that at normal condition. Incorporation of additive to methyl methacrylate has substantially enhanced grafting, tensile strength, bending strength and compression strength of the composite.

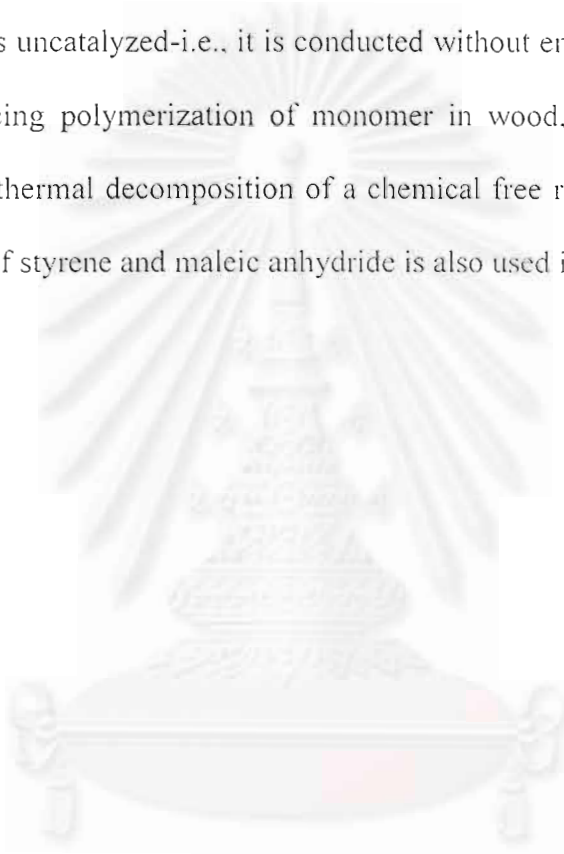
Rozman, H.D., Kumar, R.N., Abusamah, A., and Saad, M.J. [13] prepared wood-polymer composite of rubberwood by impregnating the wood with glycidyl methacrylate (GMA), combination of glycidyl methacrylate and diallyl phthalate (GMA-DAP) or diallyl phthalate (DAP) alone. Polymerization was carried out by catalytic heat treatment. The results showed that WPC based on GMA exhibited

greater dimensional stability. Flexural, compressive and impact properties for all the samples tested are improved, especially for those with higher chemical loading.

Brebner, K.I., Schneider, M.H., and Jones, R.T. [14] studied the influence of moisture content on the flexure strength of styrene-polymerized wood. They used eastern white pine and sugar maple that were impregnated and polymerized with styrene monomer and tested for flexural strength in the oven dried and air-dried condition. The eastern white pine gives in greater property enhancement than sugar maple, when the moisture content is increased from oven-dried to air-dried. Moreover, the polymer had greater effect on the strength of the air-dried maple than on the air-dried pine.

Hazer, B., Ors, Y. and Alma, H.M. [15] investigated the improvement of wood properties by impregnation with macromonomeric initiators (macroinimers) and styrene, leading to crosslinked block copolymers of styrene and poly (ethylene glycol). Weight gains of 36.37-91.13% were obtained after polymerization for 2 hours. Water uptake of the polymerized wood was found to be 35.13-72.07% and the water-repellent effectiveness of 35.14-58.15%, after a water soaking test of 144 hours. The ant swell efficiency (ASE) value increases with an increase in weight percent gain. Improvement of 19.12% in longitudinal compression and 25% in bending strength was also achieved for spruce samples with low weight percent gain. IR spectroscopy was used for chemical characterization of wood-polymer components.

Gayloard, N.G. [16] disclosed the preparation of polymer composites with porous cellulosic materials, such as wood. The process for forming such a composite involves in impregnation the wood with a polymerization complex of a monomer combination such as a complex of maleic anhydride and styrene. The polymerization is uncatalyzed-i.e., it is conducted without employing conventional means for inducing polymerization of monomer in wood, such as high-energy radiation or the thermal decomposition of a chemical free radical precursor. The stable complex of styrene and maleic anhydride is also used in this research.



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CHAPTER 3

EXPERIMENTAL PROCEDURES

3.1 Materials

3.1.1 Durianwood

The small pieces of durianwood were obtained from the wood industry. Their dimensions were 2.5 x 2.5 x 30 inches (thickness x width x length).

The surface of the wood was rough and woolly.

3.1.2 Unsaturated polyester resins

Unsaturated polyester resins (UPR) were supplied by the Siam Chemical Industry co., Ltd. The UPR in this study was Polylite SMF-811, which is a clear translucent slightly yellow liquid prepared from propylene glycol, orthophthalic anhydride and maleic anhydride. It has good curing and good mechanical properties.

Properties of Polylite SMF-811 are shown in Table 3.1.

Table 3.1 Typical data of Polylyte SMF-811 without reinforcement:

Water absorption (24 hours.)	ASTM-D-570	0.2%
Flexural strength	ASTM-D-790	12.1 kgf./mm ²
Flexure modulus	ASTM-D-790	450 kgf./mm ²
Tensile strength	ASTM-D-638	6.3 kgf./mm ²
Tensile modulus	ASTM-D-638	480 kgf./mm ²
Elongation	ASTM-D-638	2.0%
Compressive strength	ASTM-D-695	13.7 kgf./mm ²
Charpy impact strength	JIS-K-6911	2.5 kgf./cm/cm ²

3.1.3 Initiator

3.1.3.1 Benzoyl peroxide was obtained from Nippon Oil & Fats Co., Ltd.. Its tradename is NYPER BO, 50% white paste.

3.1.3.1 Methyl ethyl ketone peroxide was obtained from Elf autochem with the tradename , Peroximon K10.

3.1.4 Accelerator

In this study, cobalt octoate with 10% metal was obtained from GMG Kokkolo chemical which was used as accelerator.

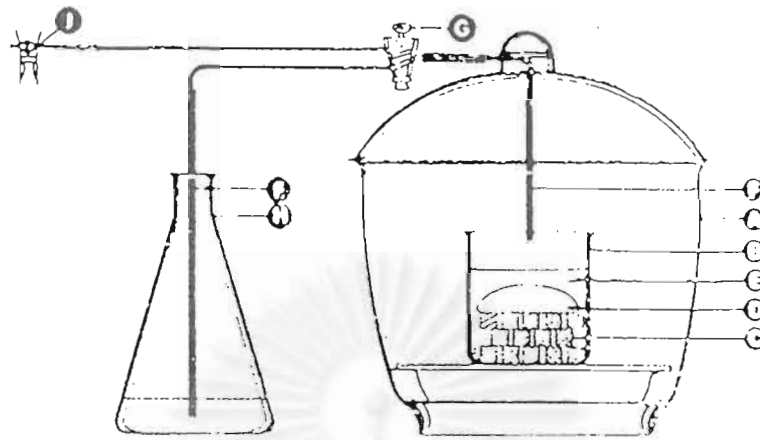
3.1.5 Chemicals

- 1) Styrene monomer, commercial grade, supplied from Siam Chemical Industry Co., Ltd.

- 2) Acetone, commercial grade, was supplied from Siam Chemical Industry Co., Ltd.
- 3) Color white, tradename Polyton white US-120-T, was supplied by Siam Chemical Industry co., Ltd.

3.2 Apparatus and equipments

1. Vacuum Chamber : modified from 8 inches diameters dessicator
2. Vacuum pump : GUASEST, Germany
3. Vernier : MITUTOYO, Japan
4. Sandpaper : WATER PROOF NO.80
5. Vacuum Oven : MUTTER, Germany
6. Balance : METTLER, England
7. Brookfield Viscometer: BROOKFIELD, United state of America
8. Universal testing machine: HOUNDFIELD 1000N
9. Scanning Electron Microscope : JSM-6400, JEOL Co., Ltd.. Japan
10. Polyvinyl chloride cups
11. Dessicator
12. Water bath



- A – Vacuum desiccator
- B – Plastic or glass treatment beaker
- C – Test wood blocks
- D – Glass or other suitable weight
- E – Treating solution
- F – Polyethylene tubing
- G – Three-way stopcock
- H – Flask containing treating solution
- I – Line to source of vacuum

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Figure 3.1 Apparatus for vacuum impregnation

3.3 Experimental Procedures

3.3.1 Preparation of Durianwood-unsaturated polyester (UPR) composites

3.3.1.1 Preparation of wood specimens

Pieces of wood were reduced to the test specimens size by using an electric saw. The rough surface was polished by sand paper in order to remove the woolly fiber and to make the surface smooth. Thus, precise measurements of the dimensions could be made.

3.3.1.2 Determination of moisture content and density of specimens

Each of the prepared test specimens were weighed accurately to 0.1 g. They were dried overnight in oven at 105 °C. The next day the dried specimens were cooled down in a dessicator and weighed again. The moisture content in each sample was calculated using the equation below.

$$\text{Moisture Content (\%)} = \frac{W_0 - W_1}{W_1} \times 100$$

Where W_0 = weight before drying

W_1 = weight after drying

The volume of each sample was determined. Density was calculated using the equation below.

$$\text{Density} = W_1 / V \quad (\text{g} / \text{cm}^3)$$

Where V = Volume of specimen after drying

3.3.1.3 Preparation of impregnation prepolymer mixture

Unsaturated polyester resin (UPR) was weighed in a plastic cup. Then, the desired amount of styrene monomer (SM) was added and mixed homogeneously. When the time to feed the prepolymer mixtures approached, the weighed curing reagent was added into the mixtures, then mixed slowly to allow the initiator to spread in all parts of the mixtures.

3.3.1.4 Preparation of durianwood-UPR composites

Each dry wood specimen was marked with waterproof ink and put into the beaker that was placed in the dessicator used as the vacuum chamber. The vacuum chamber was connected with the vacuum pump as shown in Figure 3.1. At first, the connected valve was opened and turned on the vacuum pump. The vacuum pressure was adjusted to desired levels. When gas in the dessicator was evacuated until the desired time, the vacuum pump was closed. Then the appropriate prepolymer mixture was introduced and the specimens were left immersed until atmospheric pressure was attained. The chamber was left at room temperature for a desired time, then the specimens were removed from the chamber and wiped free of excess impregnant from wood surfaces. The wood samples were wrapped in aluminium foil and then placed in an oven for curing. After unwrapping, the samples were again oven dried at 100°C for 24 hours to remove unreacted monomers. The

specimens were kept cool in the dessicator, then weighed to determine the polymer loading.

3.3.1 Study of factors effecting on the preparation durianwood-UPR composites

3.3.2.1 Determination of viscosity effecting on penetration of UPR

The viscosity significantly affected the penetration of resin into the wood pieces. In this study, UPR was diluted with styrene monomer (0%, 5%, 10%, 15% by weight) in a plastic cup. Then, the mixtures were stirred slowly to a homogeneous state. The viscosity of prepolymer mixtures was determined by a Brookfield viscometer before impregnating into the wood pieces. The impregnation parameters were as follows : 1 hour evacuating time, 2 hours soaking time and 500 mmHg evacuating pressure. Each wood specimen was weighed before and after impregnation. The penetration of UPR into durianwood depends on prepolymer loading that can be calculated by :

$$\text{Prepolymer loading (\%)} = \frac{W_1 - W_0}{W_0}$$

Where W_1 = Weight of impregnated prepolymer wood
 W_0 = Weight of untreated wood (oven dry)

3.3.2.2 Initiator type effecting on properties

Two types of initiators, benzoyl peoxide (BPO) and methyl ethyl ketone peroxide (MEKPO) in equal content (1 phr), were studied.

3.3.2.2.1 Benzoyl peroxide (BPO)

The styrene monomer content of 0%, 5%, 10% or 15% by weight was added to the prepolymer mixture in a plastic cup. Benzoyl peroxide containing 1 phr. was added in each prepolymer mixture. Impregnation parameters were as follows : 1 hour evacuating time, 500 mmHg evacuating pressure and 2 hours soaking time. After impregnation, the wood samples were wrapped in aluminum foil and then placed in an oven at 100°C for 2 hours. After unwrapping, the samples were again oven dried at 100°C for 24 hours to remove unreacted monomers.

3.3.2.2.2 Methyl ethyl ketone peroxide (MEKPO)

UPR was diluted with styrene monomer (0%, 5%, 10% or 15%) in a plastic cup. Cobalt octoate (0.001 wt% of UPR) was added and mixed together, while methyl ethyl ketone peroxide (MEKPO) was added and stirred. The impregnation parameters were as follows : 1 hour evacuating time, 500 mmHg evacuating pressure and 2 hours soaking time. After impregnation, the wood samples were wrapped in aluminum foil and then allowed to gel at room temperature for 2 hours, followed by post curing in an oven at 100 °C for 2 hours. After unwrapping, the samples were again oven dried at 100 °C for 24 hours to remove unreacted monomers.

3.3.2.3 Initiator contents effecting on properties

Initiator contents of 0.5 phr., 1 phr., 1.5 phr. or 2 phr. was added to prepolymer mixtures, that contained 10% by weight styrene monomer. For

impregnation parameters, the evacuating time was 1 hour, the soaking time was 2 hours and the evacuating pressure was 500 mmHg.

3.3.3 The study of appropriate conditions for durianwood-UPR composites preparation

3.3.3.1 Effect of evacuating time on properties

Durianwood-UPR composites were prepared from prepolymer mixtures that contained materials as follows : 90 % wg. UPR, 10% styrene monomer, 1phr initiator. The impregnation parameters were as follows: 2 hours soaking time, 500 mmHg evacuating pressure, and different evacuating times of 0.5, 1, 2, 4 hours.

3.3.3.2 Effect of soaking time on properties

Durianwood-UPR composites were prepared for prepolymer mixtures as follows : 90 % by wt. UPR, 10% by wt. styrene monomer, 1phr initiator. The impregnation parameters were as follows : 500 mmHg evacuating pressure and 1 hour evacuating time. Different soaking times of 1, 2, 4, 6 hours were studied.

3.3.4 Characterization of Durianwood-UPR Composites

3.3.4.1 Physical properties

3.3.4.1.1 Polymer loading (PL)

Before impregnation, the specimens were dried in an oven at 105 °C overnight and weighed. After impregnation the wood composite

specimens were obtained. They were weighed again, then the polymer loading was calculated as follows :

$$\text{Polymer loading (\%)} = \frac{W_t - W_0}{W_0}$$

Where W_t = Weight of treated wood or wood polymer composites

W_0 = Weight of untreated wood (oven dry)

3.3.4.1.2 Density of specimens

The weight and dimension or volume of wood composite specimens were determined. Density was calculated using the following formula:

$$\text{Density} = W / V \quad (\text{g} / \text{cm}^3)$$

W = Weight of specimens

V = Volume of specimens

3.3.4.1.3 Water absorption (WA)

Wood composite specimens were weighed to 0.1 g. accuracy, referring to the weight before water soaking. Then the specimens were submerged 25 mm. under water level in cleaning water at room temperature. After 24 hours, the specimens were taken out of the water, dabbed dry and weighed. The water absorption of the specimens was calculated as follows:

$$\text{Water absorption (\%)} = \frac{W_t - W_0}{W_0}$$

Where W_1 = Weight of specimens after water soaking
 W_0 = Weight of specimens before water soaking

The dimension of wood composite specimens was measured in radial, tangential and longitudinal directions. Thus, the volume before soaking was obtained and used to calculate the volumetric swelling coefficient (S). After soaking, the specimens were measured again. The volumetric swelling coefficient and antishrink efficiency were calculated as follows :

$$\text{Volumetric swelling coefficient (S)} = \frac{V_1 - V_0}{V_0}$$

Where V_1 = Wood volume after water soaking
 V_2 = Wood volume before water soaking

$$\text{Antishrink efficiency (ASE)} = \frac{S_1 - S_0}{S_0}$$

Where S_0 = Volumetric swelling coefficient of untreated sample
 S_1 = Volumetric swelling coefficient of treated sample

3.3.4.2 Mechanical properties

3.3.4.2.1 Hardness test [ASTM D 1324]

The hardness test is a test of the material's resistance to indentation or marring. This ASTM procedure has found general

acceptance in the industry and can be used successfully for determining the hardness of modified woods varying in density from very light to those of maximum density. This test measures the load required to imbed a 11.28 mm. diameter steel ball into wood. The depth of penetration can be determined by dial gage that can read to 0.025 mm. penetration. The speed of testing applied to the specimen test was 1.0 mm./min. The hardness modulus is calculated as follows:

$$H_m = P / 2\pi r h$$

$$= 0.717 (P / h)$$

H_m = load per unit of spherical area of penetration. MPa (or psi)

r = radius of penetration ball 5 mm. (0.222 in.)

P = arbitrarily selected load , N (or lbf) within linear portion of test data

h = depth of penetration, mm. (or in.) , at selected load

3.3.4.2.2 Flexure stress and modulus of elasticity (MOE)

[ASTM D3043-87]

Width and thickness of wood composite specimens were measured and entered into the software of the testing machine before running the test. Then flexure stress and modulus of elasticity values were obtained. The MOE corresponds to the slope of the linear portional limit, which can be calculated from the stress–strain curve as the change in stress causes a corresponding change in strain, as follows:

$$\text{Modulus of elasticity (MOE)} = \frac{L^3 \Delta W}{4 b d^3 \Delta S}$$

L = the span between the centers of supports (m)

ΔW = the increment in load (N)

b = the mean width (tangential direction) of the sample (m)

d = the mean thickness (radial direction) of the sample (m)

ΔS = the increment in deflection (m)

The dimension of testing specimen is shown in Figure 3.2

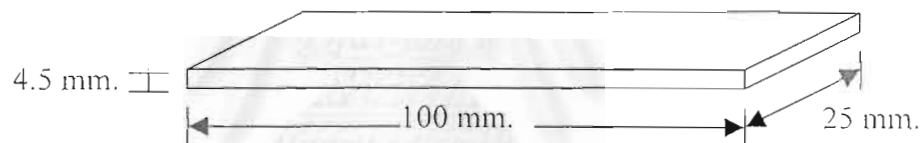


Figure 3.2 Dimension of flexure stress and MOE testing specimen.

3.3..4.2.3 Compression parallel to grain [ISO 3787]

The width and thickness of wood composite specimens were measured. Maximum load was obtained after tested. The compression parallel to grain value was calculated as follows:

$$\text{Compression parallel to grain} = \frac{P_{\max}}{a \times b}$$

where P_{\max} = the maximum load , (N)

a, b = the cross sectional dimensions of the test piece. (mm.)

The dimension of testing specimen is shown in Figure 3.3 as follows:

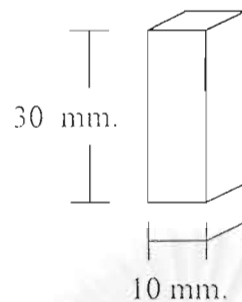


Figure 3.3 Dimension of compression parallel to grain testing specimen.

3.3.4.3 Evaluation of WPC specimens for resistance to termites

[ASTM D3345]

In this study, three types of wood, durianwood, Teakwood and Tabearkwood, were compared with WPC specimens. Prior to testing, the container was prepared by washing and rinsing it with antiseptic solution and then drying it. Each specimen was prepared as a 25.0 mm. square by 6.4 mm. in the tangential and then weighed before testing. The prepared specimens were placed on the bottom of the containers. Then 200 g. of cleaned sand was added into the container, followed by sufficient distilled water as determined in the following equation:

$$\% \text{ water to add} = \% \text{saturation} - 7.0$$

Calculate the percent saturation as follows:

$$\% \text{ saturation} = (\text{ weight of water / oven dry weight of sand}) \times 100$$

After addition of water, the container was placed overnight. The termites were weighed 1 ± 0.05 g. and added into the prepared container that had loosely closed tops. The containers were maintained at 25.5 to 27.7 °C for 4 weeks. After 4 weeks, the containers were disassembled, removed and cleaned. The test blocks were weighed again for % weight loss and then examined visually using the following rating system:

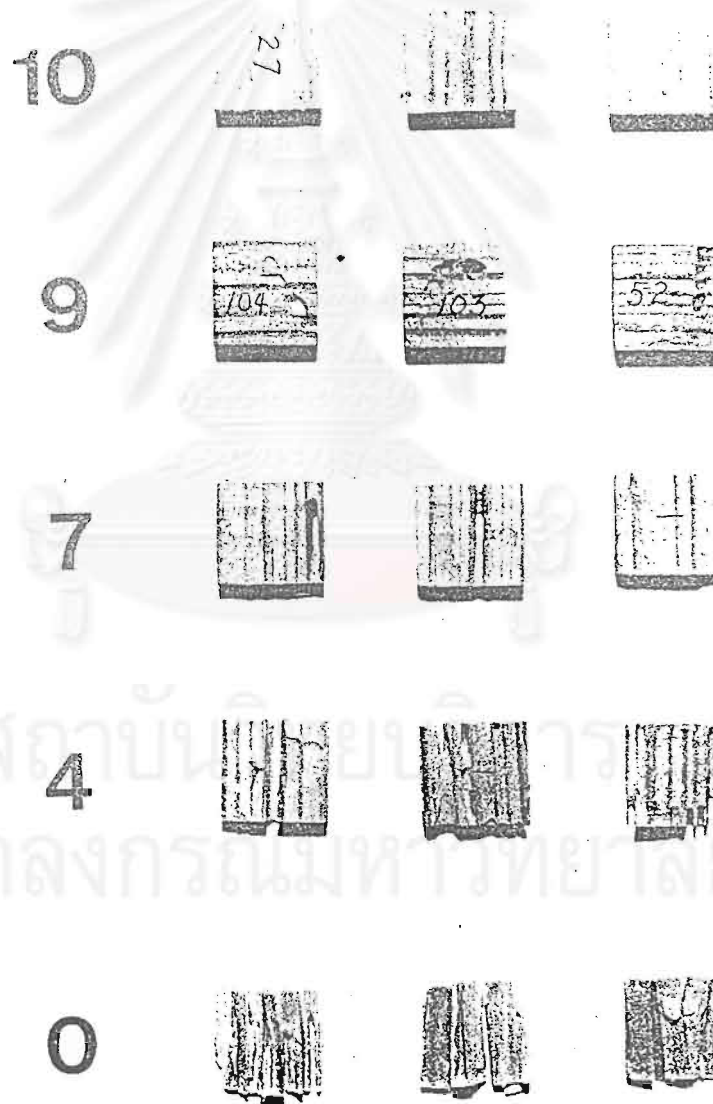


Figure 3.4 Typical ratings of termite attack on test blocks

10 = Sound, surface nibbles permitted

9 = Light attack

7 = Moderate attack, penetration

4 = Heavy

0 = Failure

3.3.4.4 Microstructure of WPC Specimens

Microstructure of wood-polymer composite specimens was observed by a scanning electron microscope and compared with the microstructure figure of natural durianwood. The specimens were dried then coated with gold before scanning observation.

CHAPTER 4

RESULT AND DISCUSSION

Modified durianwood can be defined as a wood-polymer composite material with properties that have been changed in comparison to natural wood. The durianwood was impregnated by unsaturated polyester resins and then heated to dry and cure the modifiers. The durianwood modification improves different wood properties and increases the material durability. It allows material consumption to be reduced and also widens the end use of the wood.

4.1 Characteristic of durianwood materials

In this study, only local durianwood was studied, therefore, the durianwood should be characterized both physically and mechanically before the study. The results of characterization are presented in Table 4.1.

Table 4.1 Characteristic of durianwood materials

Properties	Durianwood
Density (g/cm ³)	0.55
Hardness (MPa)	22.23
MOE (MPa)	5730
Flexural stress (MPa)	89.24
Compression (N/mm ²)	52.53

4.2 Determination of viscosity effecting penetration of UPR

Since the viscosity of prepolymer mixture prepared from commercial UPR is too high, therefore, it cannot penetrate into the durianwood matrix. Thus the diluent, which reduced the viscosity of UPR, was added in order to increase the ability of the resin to penetrate the wood. In this study, styrene was used as a reactive diluent that could reduce viscosity of the resin and miscibility of the polyester. As shown in Figure 4.1, the viscosity of UPR was reduced accordingly when the amount of styrene monomer was increased, which resulted in the increase of penetration of resin into the wood. The resin could be diluted with styrene monomer upto 5%. But, after 5% styrene monomer, the rate of penetration was reduced. In order to select the suitable amount of diluent for dissolving the impregnated samples, the effect of other properties was studied accordingly.

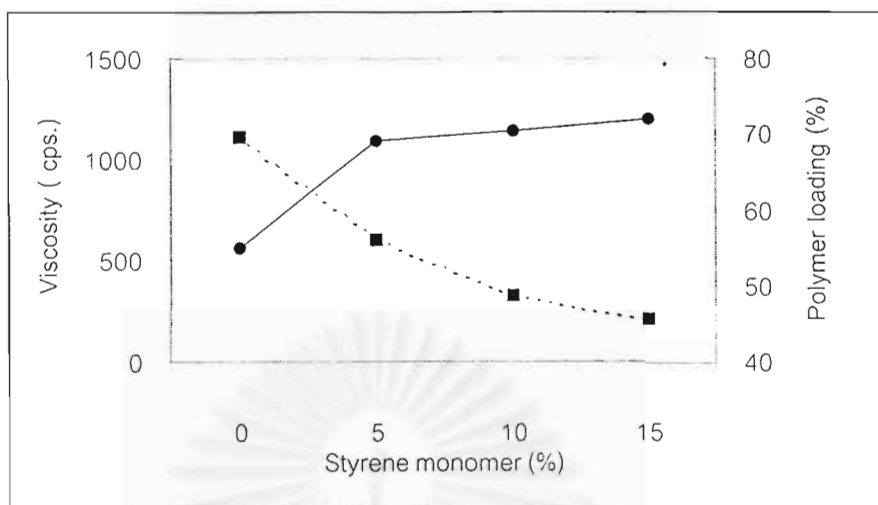


Figure 4.2 Relationship between viscosity of UPR and penetration of UPR into durianwood

4.3 Effect of initiator type on properties

As the diluent content increased, the properties of the wood would be changed. In this study two types of initiators, benzoyl peroxide (BPO) and methyl ethyl ketone peroxide (MEKPO), were studied.

4.3.1 Effect of benzoyl peroxide on properties

Benzoyl peroxide is the most popular medium temperature peroxide initiator (60-120°C). It is stable at room temperature, but decomposes readily at elevated temperatures. In this experiment, 1% benzoyl peroxide was used with 0%, 5%, 10% and 15% styrene monomers. Parameters of the impregnation process were as follows: 1 hour evacuating time, 2 hours soaking time, 500 mmHg evacuating

pressure. Properties of the impregnated samples are shown in Table 4.2 and are illustrated in Figure 4.2

Table 4.2 Properties of durianwood-UPR prepared from benzoyl peroxide and different contents of diluent

Physical Properties	% Styrene monomer			
	0	5	10	15
Polymer loading (%)	54.64	68.28	71.42	71.70
Density (g /cm ³)	0.744	0.863	0.850	0.861
Water adsorption (%)	19.44	11.26	12.68	12.97
Antishrink efficiency	24.80	35.12	33.54	34.35

Mechanical Properties	% Styrene monomer			
	0	5	10	15
Polymer loading (%)	55.00	69.02	70.42	71.80
Hardness (MPa)	31.48	44.21	36.93	37.40

Polymer loading (%)	67.09	69.83	68.60	73.39
MOE (MPa)	8120	8271	11856	9745
Flexural stress (MPa)	114	114	178	156

% Polymer loading	61.56	82.15	79.80	79.79
Compression (MPa)	74.96	68.29	76.37	75.71

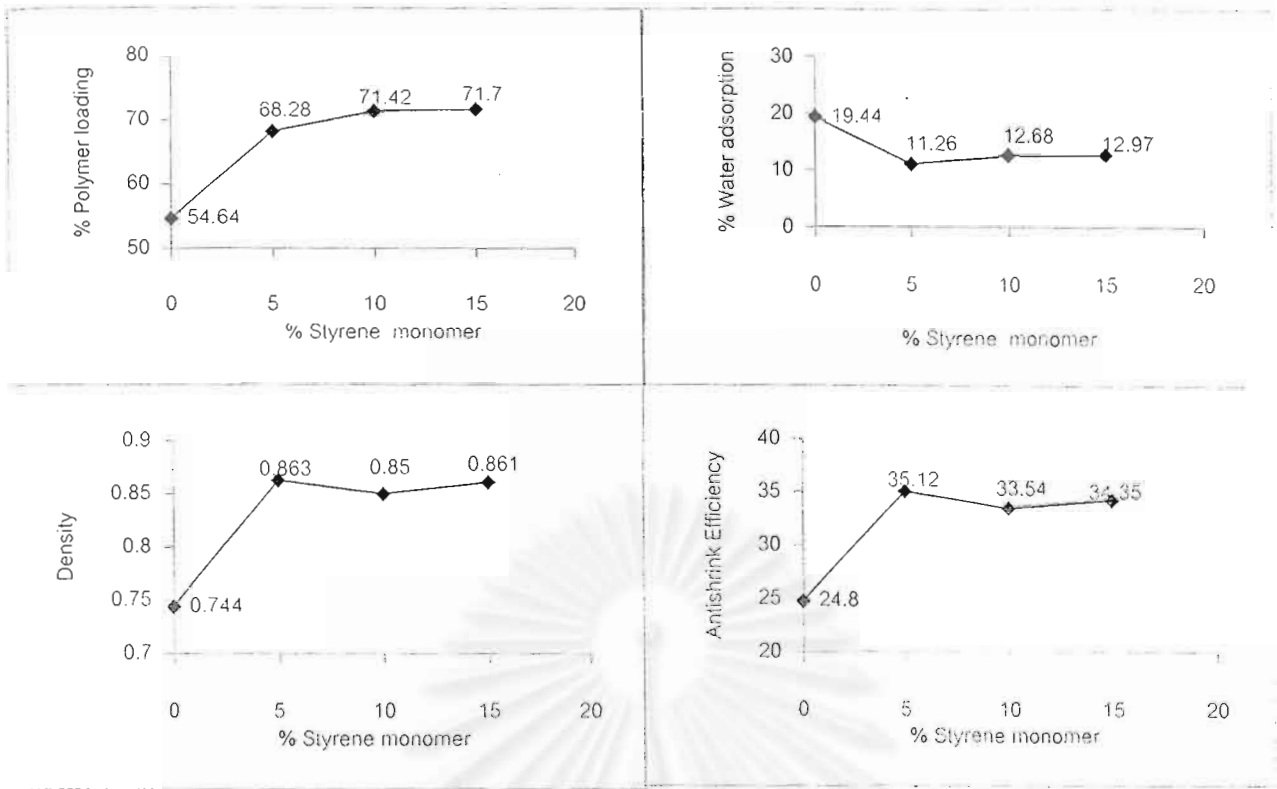


Figure 4.2 Physical properties of durianwood-UPR composites prepared from benzoyl peroxide and different contents of diluent

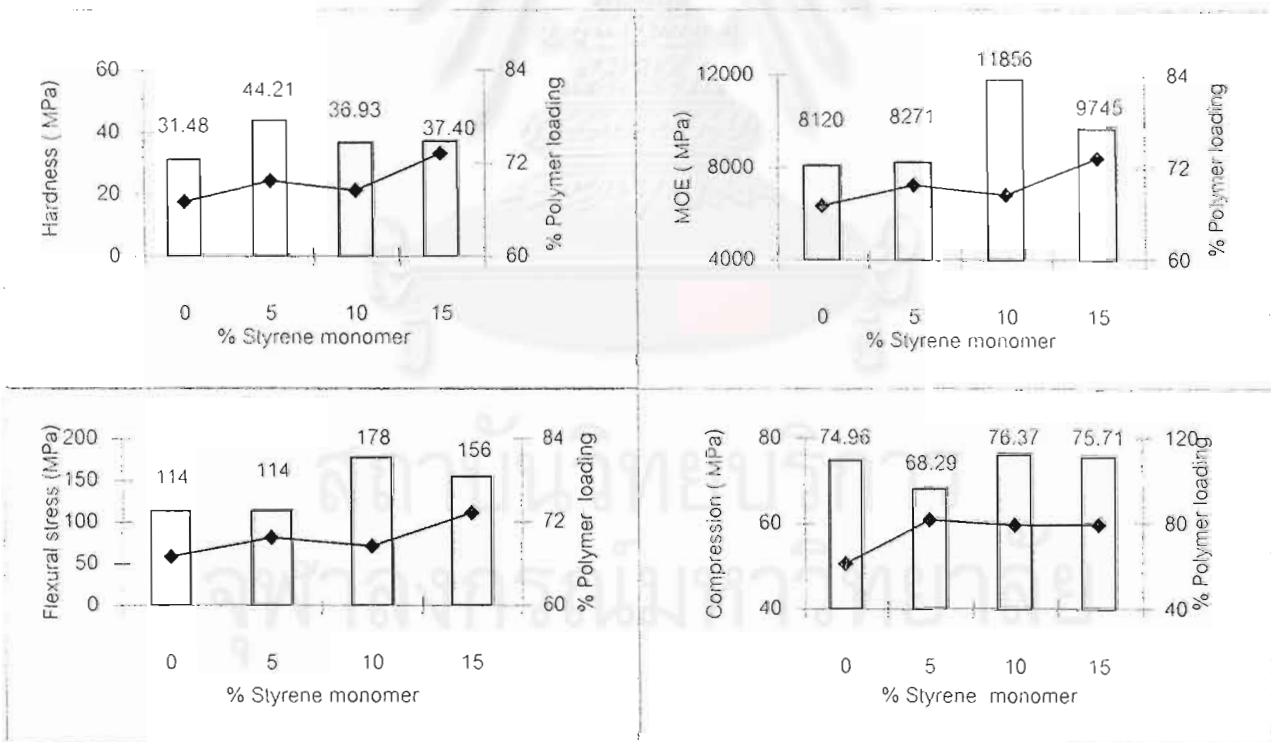


Figure 4.3 Mechanical properties of durianwood-UPR composites prepared from benzoyl peroxide and different contents of diluent.

Polymer loading (PL.) of wood-polymer composites prepared from varying diluent contents of prepolymer mixtures showed that polymer loading increased with increasing diluent content. Therefore, the mixture could flow easily through the wood grains, resulting in more polymer, retaining in void spaces and increasing the density of wood.

Water absorption of impregnated samples was reduced with increasing polymer loading. This could be explained by the increasing amount of polymer that can fill up the lumen of wood, resulting in the reduction of absorbing moisture by the hydroxyl groups of wood cell wall, which would consequently increase in antishrink efficiency (ASE). The effects on mechanical properties were determined and illustrated in Figure 4.3.

Mechanical properties were shown in longitudinal bar and polymer loading of each sample shown in graphic data. These results showed that higher diluent contents gave higher polymer loading, but differed in mechanical properties such as hardness. At 15% diluent content showed the highest value. The modulus of elasticity (MOE) and flexural stress showed high values at 10% diluent content. The compression parallel to grain of samples showed similar values.

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4.3.2 Effect of methyl ethyl ketone peroxide on properties

Methyl ethyl ketone peroxide (MEKPO) is the most widely used low-temperature peroxide (20-60°C) initiator. It does not lead to a full cure by itself at ambient temperature. However, with the addition of an accelerator, cobalt octoate, the catalyst will cause gelation and almost complete cure. In this study, the prepolymer mixture containing 1% MEKPO, 0.001 cobalt octoate and varying diluent content from 0%, 5%, 10% and 15%, respectively. Parameters of impregnation process were as follows: 1 hour evacuating time, 2 hours soaking time, 500 mmHg evacuating pressure. Impregnated samples gave the properties presented in Table 4.3 and illustrated in Figure 4.4 and Figure 4.5.

Table 4.3 Properties of durianwood-UPR prepared from MEKPO and different contents of diluent

Physical Properties	% Styrene monomer			
	0	5	10	15
Polymer loading (%)	50.47	66.73	72.86	73.98
Density (g /cm ³)	0.757	0.797	0.803	0.868
Water adsorption (%)	13.82	13.28	8.14	11.40
Antishrink efficiency	26.76	36.43	35.24	36.00

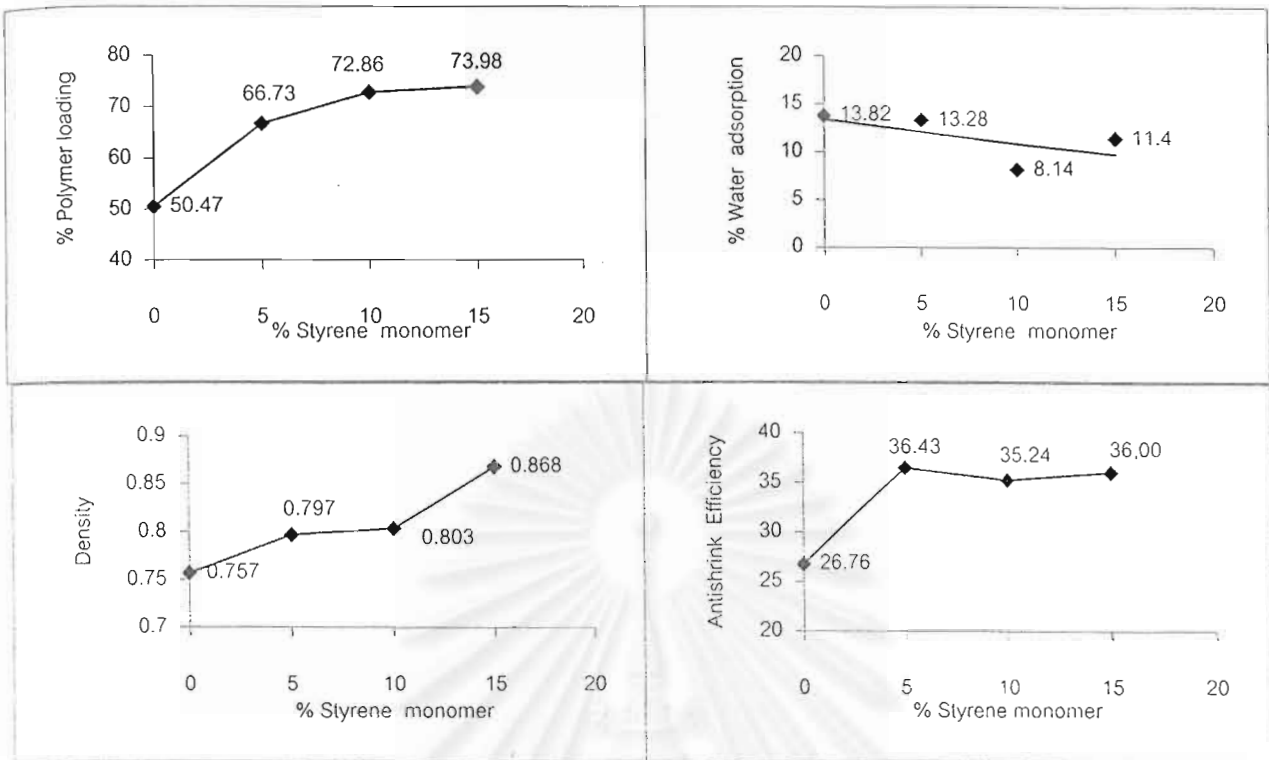


Figure 4.4 Physical properties of durianwood-UPR composites prepared from MEKPO and different contents of diluent.

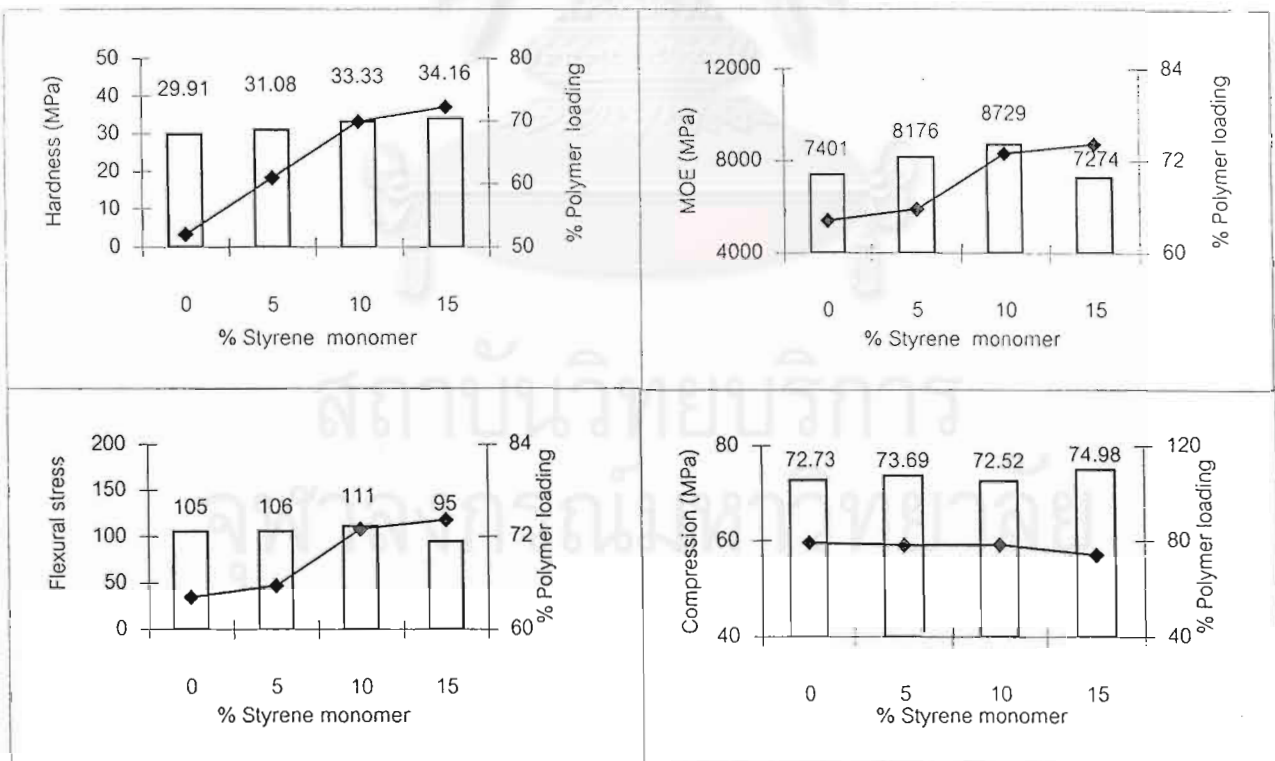


Figure 4.5 Mechanical properties of durianwood-UPR composites prepared from MEKPO and different contents of diluent.

Table 4.3 Properties of durianwood-UPR prepared from MEKPO and different contents of diluent (continued)

Mechanical Properties	% Styrene monomer			
	0	5	10	15
Polymer loading (%)	52.00	61.03	70.01	72.31
Hardness (MPa)	29.91	31.08	33.33	34.16
Polymer loading (%)	64.18	65.66	72.99	74.18
MOE (MPa)	7401	8176	8729	7274
Flexural stress (MPa)	105	106	111	95
% Polymer loading	79.26	78.07	78.46	74.08
Compression (MPa)	72.73	73.69	72.52	74.98

Physical properties of the samples prepared from MEKPO tended to be similar to the samples prepared from BPO, which corresponded to the polymer loading when the diluent content increased. The polymer loading will increase, resulting in density and antishrink efficiency increase too.

Figure 4.5 shows that some mechanical properties, such as hardness and compression were not significantly different, the values were similar. The modulus of elasticity and flexural stress showed highest values at 10% styrene content at 8729 and 111 MPa, respectively.

At 10% styrene monomer, both BPO and MEKPO gave better properties than others because the resins having high styrene content exhibited high shrinkage on curing. Because of the styrene monomer was evaporated before curing completely resulting in the decrease of impregnated wood properties. On the other hand, resins with too low styrene content have the tendency not to cure fully.

When the properties of BPO treated samples and MEKPO treated samples were compared, they indicated that samples treated with BPO gave better properties than those treated with MEKPO as shown in Table 4.4.

Table 4.4 Comparison of properties of samples treated with BPO and MEKPO

Physical properties	BPO	MEKPO
Polymer loading (%)	71.42	72.86
Density (g /cm ³)	0.850	0.803
Water adsorption (%)	12.68	8.14
Antishrink efficiency	33.54	35.24

Table 4.4 Comparison of properties of samples treated with BPO and MEKPO

(continued).

Mechanical properties	BPO	MEKPO
Polymer loading (%)	70.42	70.01
Hardness (MPa)	36.93	33.33
Polymer loading (%)	68.60	72.99
MOE (MPa)	11856	8729
Flexural stress (MPa)	178	111
% Polymer loading	79.30	72.52
Compression (MPa)	76.37	78.46

4.4 Effect of initiator content on properties

As the concentration of the initiator increased, the properties of impregnated wood were expected to change. The initiator contents were varied from 0.5, 1.0, 1.5 and 2.0 phr. Parameters of impregnation process were as follows: 1 hour evacuating time, 2 hours soaking time, 500 mmHg evacuating pressure. Impregnated samples gave the properties presented in Table 4.5, Figure 4.6 and 4.7.

Table 4.5 Properties of durianwood-UPR resins composites prepared from various initiator contents.

Physical Properties	Initiator content (phr.)			
	0.5	1.0	1.5	2.0
Polymer loading (%)	73.30	71.42	72.62	73.61
Density (g /cm ³)	0.840	0.850	0.849	0.859
Water adsorption (%)	11.04	12.68	9.24	12.90
Antishrink efficiency	34.95	33.54	35.56	38.46

Mechanical Properties	Initiator content (phr.)			
	0.5	1.0	1.5	2.0
Polymer loading (%)	70.05	71.25	69.05	72.53
Hardness (MPa)	29.21	36.93	35.12	32.44

Polymer loading (%)	65.86	68.60	63.17	70.47
MOE (MPa)	9375	11856	9288	9421
Flexural stress (MPa)	144	178	142	143

% Polymer loading	78.79	79.8	77.46	71.72
Compression (MPa)	70.78	76.37	76.22	80.11

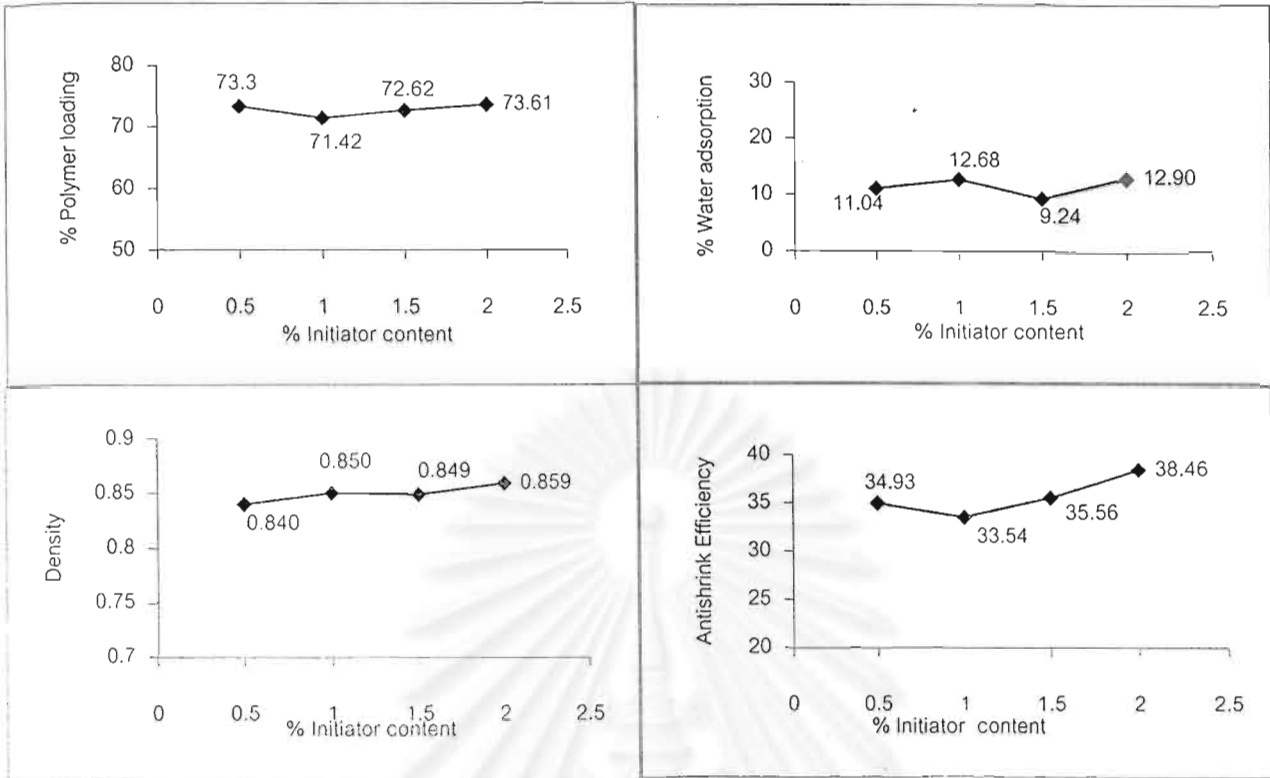


Figure 4.6 Physical properties of durianwood-UPR composites prepared from various initiator contents

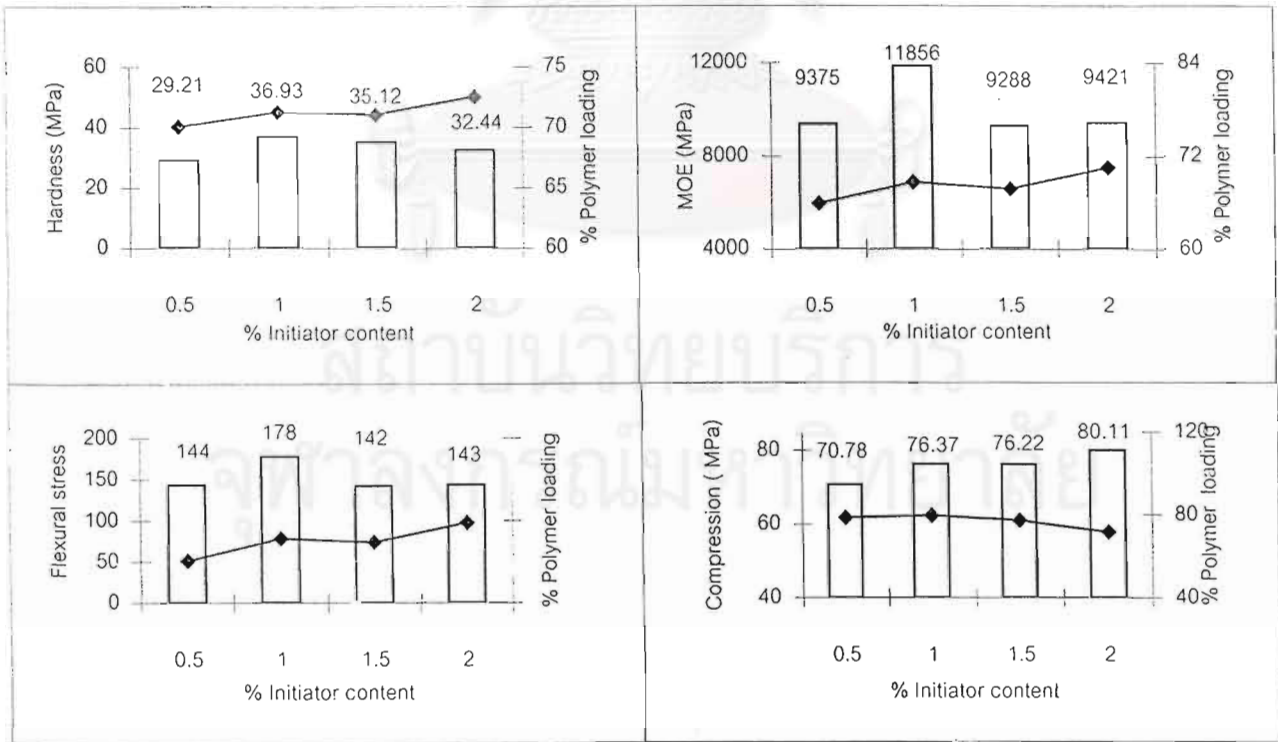


Figure 4.7 Mechanical properties of durianwood-UPR composites prepared from various initiator contents

Physical properties of impregnated samples with various initiator contents showed that there were no significant differences in polymer loading, resulting in the density of treated samples having close values in each initiator content. The water adsorption and antishrink efficiency behaved in the same way.

Mechanical properties of impregnated samples such as hardness, modulus of elasticity (MOE), and flexural stress, impregnated with 1.0 phr. initiator showed higher values than those of the other. Compression parallel to grains of samples showed the highest values at 2.0 phr. initiator.

These experimental results showed that samples impregnating with 1 phr. initiator in prepolymer mixture gave the superior mechanical properties.

4.5 Effect of evacuating time on the properties of impregnated samples

Evacuating time is the time used to evacuate air from the void spaces of wood cells. It was assumed that the longer the evacuating time, the more void space that was free of air was obtained. Thus, it was a benefit for prepolymer mixtures to penetrate the wood cells. In this study the evacuating time was varied from 0.5, 1, 2, 4 hours. Results of this experiments are shown in Table 4.6 and illustrated in Figures 4.8 and 4.9.

Table 4.6 Properties of durianwood-UPR composites prepared from various evacuating times.

Physical Properties	Evacuating time (hrs.)			
	0.5	1.0	2.0	4.0
Polymer loading (%)	53.23	71.42	72.58	73.26
Density (g/cm ³)	0.762	0.850	0.827	0.859
Water adsorption (%)	10.71	12.68	10.01	11.70
Antishrink efficiency	31.29	33.54	35.16	35.59

Mechanical Properties	Evacuating time (hrs.)			
	0.5	1.0	2.0	4.0
Polymer loading (%)	52.01	71.42	73.08	73.59
Hardness (MPa)	35.52	36.93	34.08	32.50

Polymer loading (%)	61.73	68.60	72.08	71.71
MOE (Mpa)	9513	11856	10561	10558
Flexural stress (MPa)	142	178	159	163

% Polymer loading	75.03	79.80	78.50	80.32
Compression (MPa)	55.71	76.37	79.57	71.55

The results of the physical properties test showed that 1, 2 and 4 hours of evacuating time, gave higher polymer loading than 0.5 hour evacuating time. The long evacuating time gave the ability to evacuate air from the wood cells. Thus,

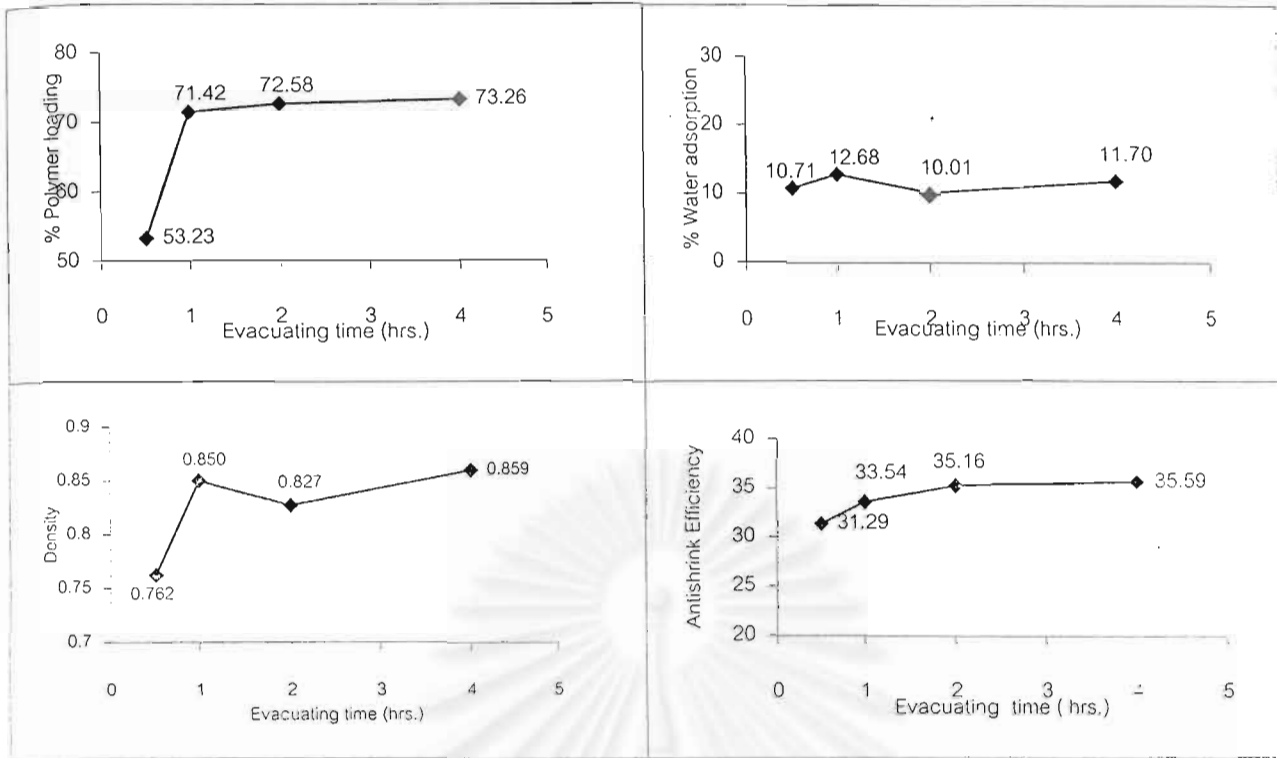


Figure 4.8 Effect of evacuating time on the physical properties of impregnated samples

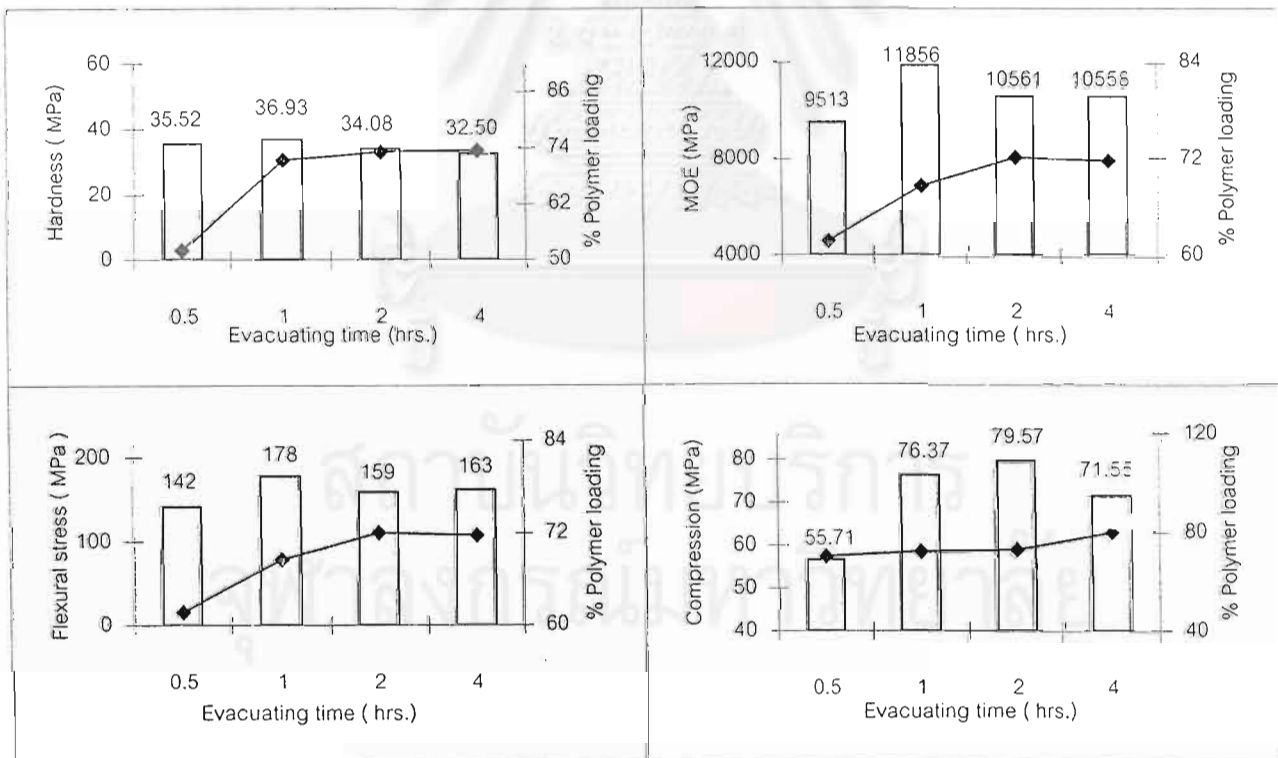


Figure 4.9 Effect of evacuating time on the mechanical properties of impregnated samples

allowed the opportunity for the prepolymer mixture to penetrate into empty wood cells and to be retained in there. More polymer filled in the wood cells resulted in reduced water absorption. Since the water was not absorbed into the wood cell, thus, dimension of wood would not change and ASE of treated samples increased accordingly too. However, there was no significant difference in polymer loading between the specimens obtained from 1, 2 and 4 hours. Thereby physical properties of these specimens were similar.

Mechanical properties of various evacuating time samples are shown in Figure 4.9. Mechanical properties corresponded with polymer loading. When polymer loading increased, more resin could be penetrated into the void space of wood for reinforcement, which increased rapidly between the evacuated times of 0.5 to 1 hour. After that the values of polymer loading were similar. Therefore, the evacuating time of 1 hour was enough for preparing durianwood-impregnated samples.

From all of the test results, an evacuating time of 1 hour improved the physical properties and mechanical properties of the treated samples. Therefore, the evacuating time of 1 hour was used to study the effect of evacuating pressure on properties of impregnated samples.

4.6 Effect of soaking time on the properties of impregnated samples

Soaking time is important in the impregnation process. It is the period used to soak the specimens in the polymerizable mixtures. The soaking times were varied from 1, 2, 3 and 6 hours. Then impregnating parameters were fixed as 1 hour

evacuating time and 500 mmHg evacuating pressure. Properties of the impregnated samples are shown in Table 4.7 and are illustrated in Figures 4.10 and 4.11.

Table 4.7 Properties of durianwood-UPR composites prepared by varying soaking times

Physical Properties	Soaking time (hrs.)			
	1.0	2.0	3.0	6.0
Polymer loading (%)	57.35	71.42	91.33	100.05
Density (g /cm ³)	0.810	0.850	0.841	0.844
Water adsorption (%)	10.81	12.68	7.95	6.98
Antishrink efficiency	37.61	33.54	51.26	52.47

Mechanical Properties	Soaking time (hrs.)			
	1.0	2.0	3.0	6.0
Polymer loading (%)	52.05	71.42	76.65	85.21
Hardness (MPa)	36.56	36.93	41.69	40.09

Polymer loading (%)	51.75	68.60	73.73	75.00
MOE (MPa)	9200	11856	11790	10524
Flexural stress (MPa)	133	178	180	157

% Polymer loading	67.27	79.30	88.71	85.82
Compression (MPa)	65.31	76.37	75.90	85.68

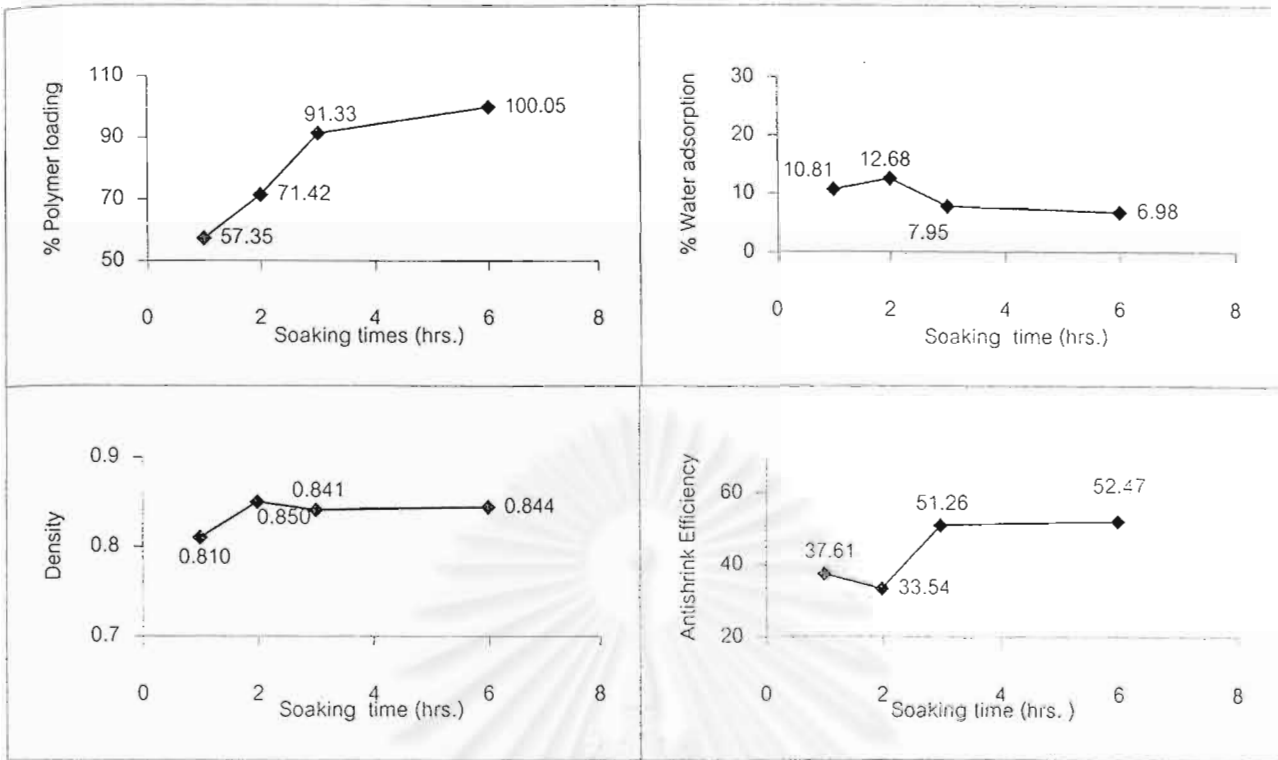


Figure 4.10 Effect of soaking time on the physical properties of impregnated samples

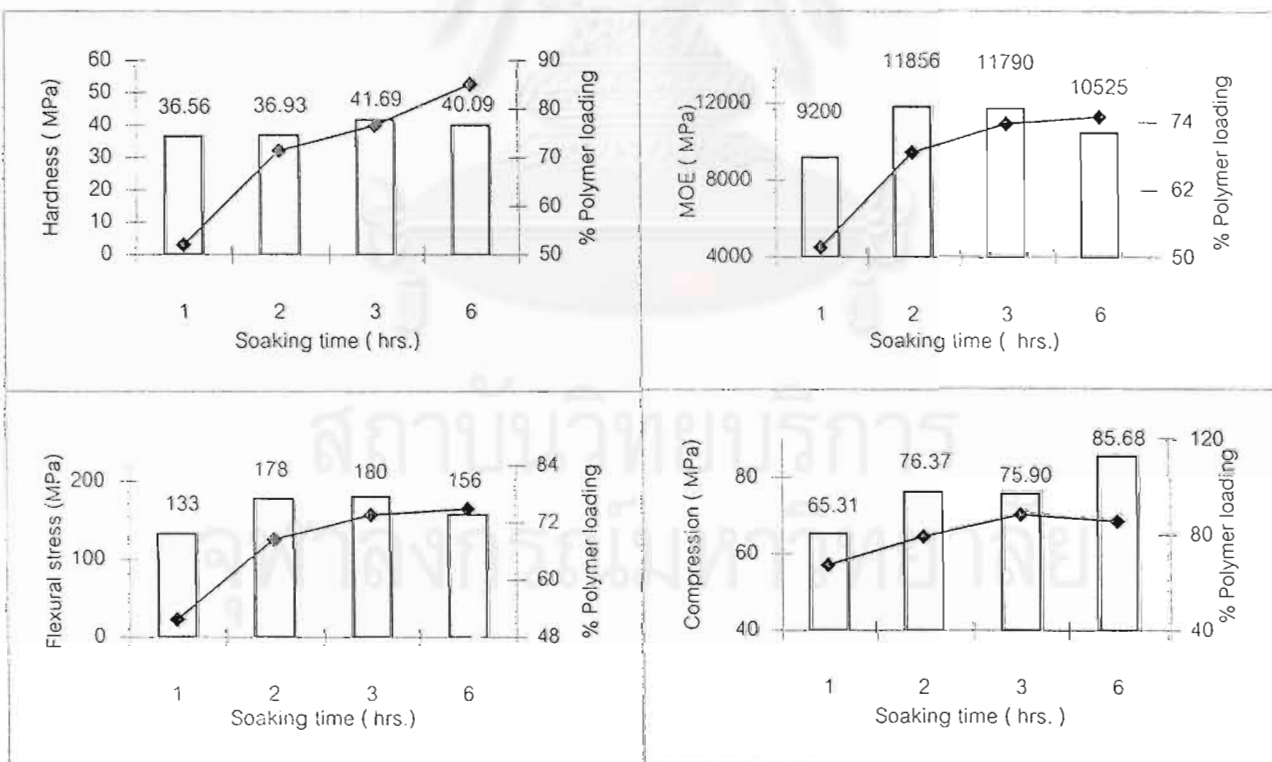


Figure 4.11 Effect of soaking time on the mechanical properties of impregnated samples

The results of physical properties testing showed that, polymer loading of 1, 2, 3 and 6 hours soaking time were 10.81, 12.68, 7.95, 6.98. antishrink efficiencies were 37.61, 33.54, 51.26, 52.47 and the densities were 0.810, 0.850, 0.841, 0.844 respectively. These results showed that when the evacuating time was increased to 6 hours, the polymer loading could increase to 100%. But water adsorption and antishrink efficiency could improve properties the most at only 3 hours. Both 3 and 6 hours soaking samples showed no significant improvement. The mechanical property results are illustrated in Figure 4.9.

Hardness testing samples soaked at 1, 2, 3 and 6 hours were 36.56, 36.93, 41.69, 40.09 MPa. MOEs were 9200, 11856, 11790, 10524 MPa. flexural stress were 133, 178, 180, 157, respectively. From these results, it indicates that longer soaking time gives higher polymer loading, which results in improved MOE and flexural stress.

Compression parallel to grain testing of samples soaked at 1, 2, 3, 6 hours gave 65.31, 76.37, 75.90, 85.68 N/mm² compression values. The polymer loadings were increased according to the soaking time. The higher polymer loading obtained from longer soaking time gave higher compression parallel to grain values. This was because wood is contained as a bundle of straws bound together and a compression parallel to grain could be thought of as a force trying to compress the straws from end to end. If the polymer contained in wood cells was high, it would increase the stiffness of the straws and result in high compression values.

A soaking time of 3 hours is the period in which treated samples showed the highest polymer loading . Thus, 3 hours soaking time was selected for the next experiment.

4.7 Evaluation of WPC specimens for resistance to termites

The annual loss in forest products of various kinds is due to deterioration by wood-boring insects such as the 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, four types of woods were controlled under the same condition such as untreated durianwood, durianwood treated with UPR, teakwood and tabeakwood. The results are shown in Table 4.8 and Table 4.9.

Table 4.8 The results of wood before and after testing resistance to termites

Types of wood	Wt. before test (g)	Wt. after test (g)	Weight loss (%)
Durianwood	1.44	1.34	6.94
UPR-durianwood composites	2.46	2.39	2.85
Teak	1.72	1.70	1.16
Tabeak	1.75	1.74	0.57

Table 4.9 The result of rating of termite attack

Types of wood	Rating of termite attack
 <p data-bbox="512 831 683 869">Durianwood</p>	9
 <p data-bbox="475 1193 715 1232">UPR-Durianwood</p>	9
 <p data-bbox="563 1563 635 1601">Teak</p>	9
 <p data-bbox="544 1928 659 1966">Tabeark</p>	10

From this experiment with the containers holding combinations of untreated durianwood, durianwood treated with resin, teakwood and tabearkwood. we found that termites tended to bore through untreated durianwood more than others. which had the highest weight loss of 6.94 % by wt. teakwood and treated durianwood damaged less, whereas tabearkwood was not damaged. Thus. there was little weight loss. Therefore, the durianwood impregnated with UPR can be more resistant to termites than untreated durianwood.

4.8 Scanning Electron Microscopy (SEM) of WPC

The microstructures of wood-polymer composite (WPC) were examined by scanning electron microscopy (SEM) of transverse sections of the specimens. The microstructures of untreated durianwood cells are shown in Figures 4.10 and 4.11. The microstructures of impregnated wood cells are shown in Figures 4.12 and 4.13.

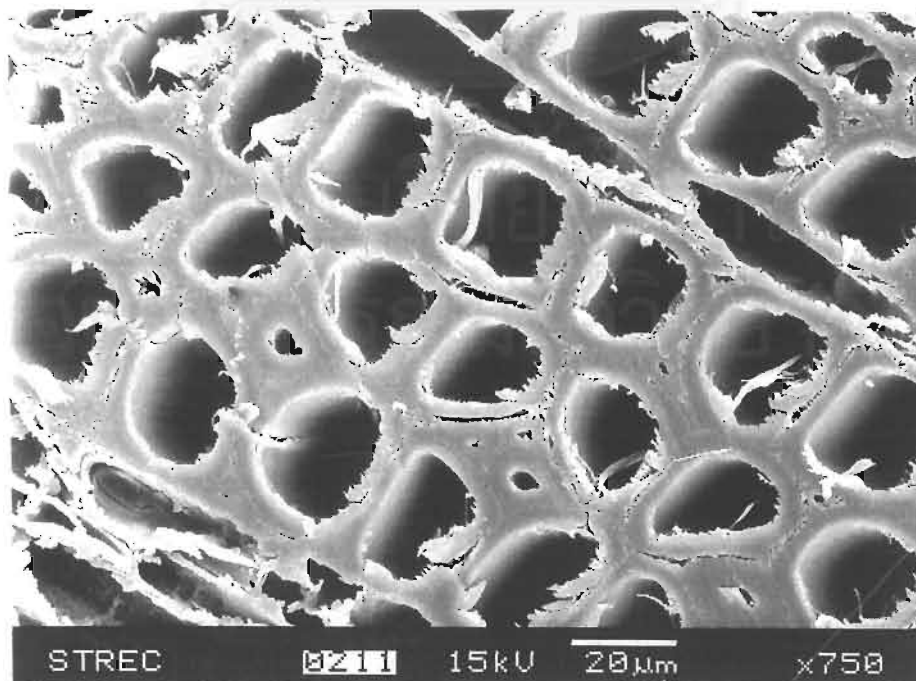


Figure 4.12 SEM micrograph of transverse section of empty wood cells (750x)

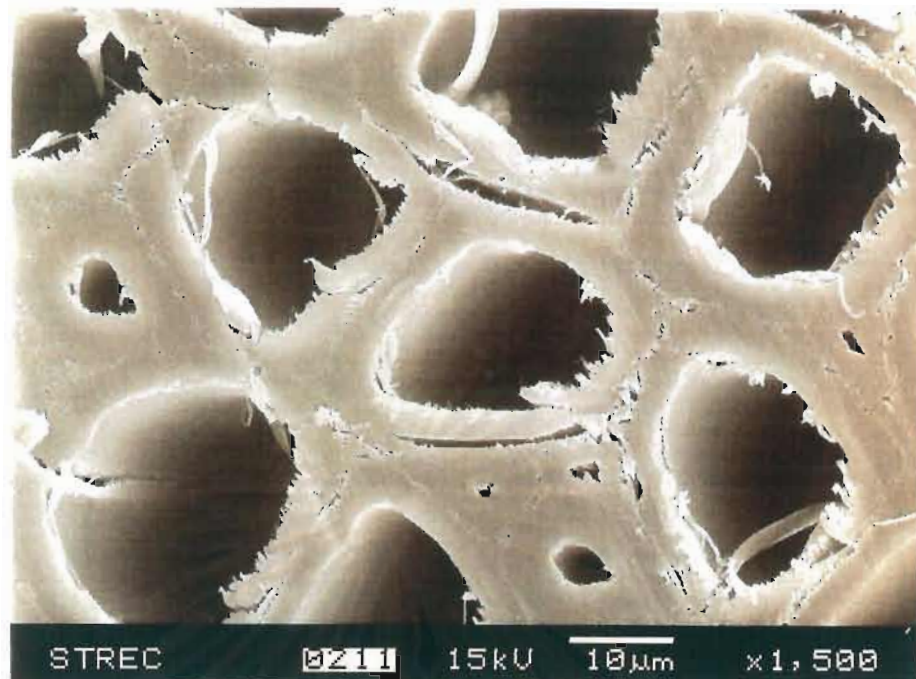


Figure 4.13 SEM micrograph of transverse section of empty wood cells (1500x)



Figure 4.14 SEM micrograph of transverse section of polymer filled cells (750x)



Figure 4.15 SEM micrograph of transverse section of polymer filled cells (1500x)

From Figures 4.12 and 4.14, the microstructure of untreated durianwood cells showed the empty void spaces. In the impregnation process, the empty wood cells were fully filled with polymer. This was an important consequence on improvement in physical properties and mechanical properties of natural wood.

4.9 Application of durianwood-UPR composites

In this study, the durianwood was improved both physically and mechanically and showed to be better than the hardwood. The comparison of wood properties shown is in Table 4.14.

Table 4.14 Comparison of the properties of UPR-durianwood with other woods

Properties	Type of wood			
	Durianwood	UPR-durianwood composites	Epoxy-rubberwood composites	Teakwood
Density	0.550	0.841	0.860	0.650
Hardness (MPa)	22.23	41.69	-	30.14
MOE (MPa)	5730	11790	9271	8331
Flexure stress (MPa)	89.24	180	154	110
Compression (N/mm ²)	52.53	75.90	72.00	75.45

Table 4.14 indicates that durianwood impregnated with UPR has better mechanical properties than untreated durianwood. When comparing it with epoxy-rubberwood composites prepared by the same process from Rungvichaniwat, C. ref. (17), the UPR-durianwood had better mechanical properties. This property of treated wood is higher than teakwood, but lower than tabarkwood. Therefore, treated durianwood can replace teakwood such as flooring material, furniture articles, household items, etc..

For this research, the treated durianwood was applied to be a flooring material. mosaic. When mosaic is already prepared, it has aesthetic properties of wood that shown in Figure 4.16.



Figure 4.16 The mosaic that prepared from treated durianwood

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CHAPTER 5

CONCLUSION

The wood-polymer composites prepared from durianwood impregnated with unsaturated polyester resins in this research can improve both the physical and mechanical properties. The chosen method is impregnation under reduced pressure and curing resins with a heat-catalyst method. The optimum conditions for durianwood-UPR composites preparation are as follows :

Unsaturated polyester resins	90 %	by weight
Reactive diluent	10 %	by weight
Benzoyl peroxide	1	phr.
Evacuating time	1	hours.
Soaking time	3	hours.
Evacuating pressure	500	mm.Hg

Durianwood-UPR composites obtained under these condition gave high polymer loading resulting in improved properties such as water absorption was reduced by about 86% and density was increased about 53 % when compared with untreated durianwood. This resulted in high antishrink efficiency (ASE) in dimension stability.

For mechanical properties, the hardness was improved by about 88 %. the modulus of elasticity (MOE) was improved by about 105 %, the flexural stress was improved by about 101% and compression parallel to grain improved by about 44% from the untreated durianwood. Some improved mechanical properties are better than Teakwood such as, hardness, MOE and flexural stress.

Resistance to termites was better after testing which was compared with untreated durianwood, teakwood and tabeakwood. The results showed that impregnation durianwood with UPR almost completely resisted damage by termites in one month as same as tabeakwood.

The investigation of microstructure of impregnated which durianwood showed that the lumen of wood could be filled fully with UPR when compared with untreated durianwood. This resulted in highly improve mechanical properties.

In their applications, the durianwood can be used as flooring material because of the mechanical properties which are as high as teakwood and because of the beautiful wood grains when coating with lacquer.

Suggestions for Future work

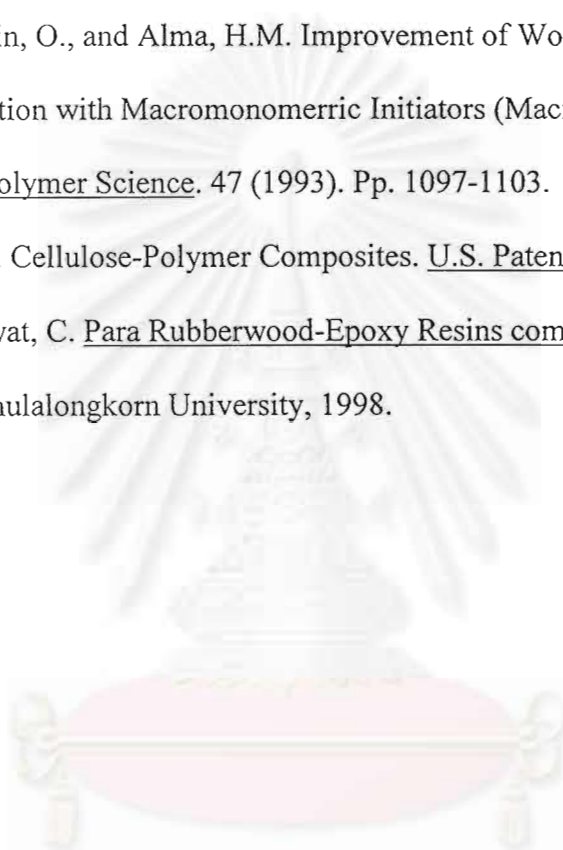
1. To study the method and conditions in order to enlarge the scale to produce the durianwood-polyester composites for industrial.
2. To study other low quality woods for value added in economics.

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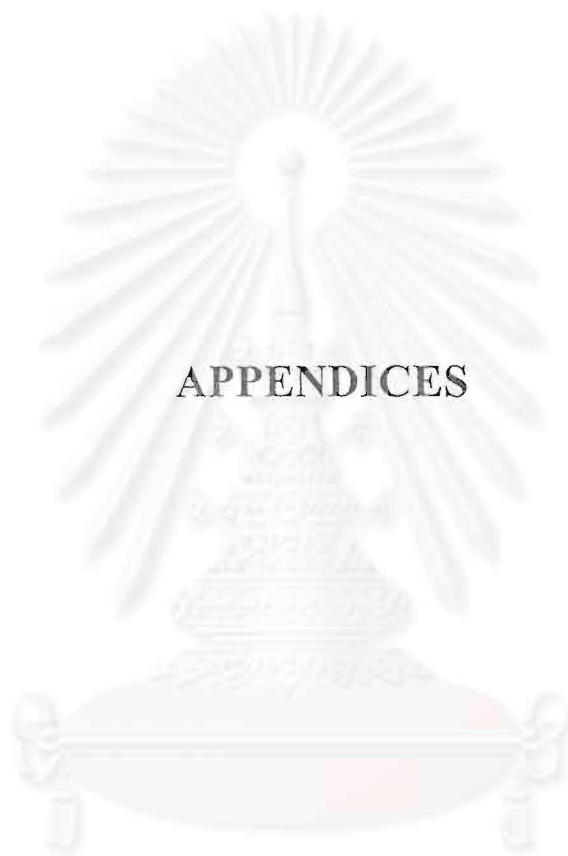
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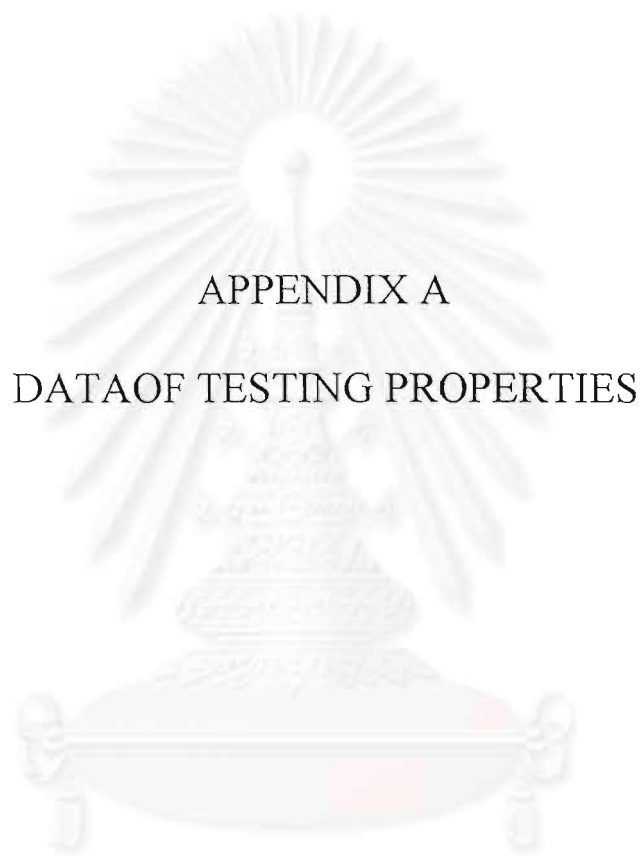


จุฬาลงกรณ์มหาวิทยาลัย



APPENDICES

สถาบันวิทยบริการ
จุฬาลงกรณ์มหาวิทยาลัย



สถาบันวิทยบริการ
จุฬาลงกรณ์มหาวิทยาลัย

Table A The parameters for preparation of durianwood-UPR composites.

WPC	Diluent types	Diluent content(%)	Initiator content(%)	Evacuating time(hrs.)	Soaking time(hrs.)	Evacuating Pressure mm.Hg.
A	BPO	0%	1.0	1.0	2.0	500
B	BPO	5%	1.0	1.0	2.0	500
C	BPO	10%	1.0	1.0	2.0	500
D	BPO	15%	1.0	1.0	2.0	500
E	MEKPO	0%	1.0	1.0	2.0	500
F	MEKPO	5%	1.0	1.0	2.0	500
G	MEKPO	10%	1.0	1.0	2.0	500
H	MEKPO	15%	1.0	1.0	2.0	500
I	BPO	10%	0.5	1.0	2.0	500
J	BPO	10%	1.5	1.0	2.0	500
K	BPO	10%	2.0	1.0	2.0	500
L	BPO	10%	1.0	0.5	2.0	500
M	BPO	10%	1.0	1.0	2.0	500
N	BPO	10%	1.0	2.0	2.0	500
O	BPO	10%	1.0	4.0	2.0	500
P	BPO	10%	1.0	1.0	1.0	500
Q	BPO	10%	1.0	1.0	3.0	500
R	BPO	10%	1.0	1.0	6.0	500

Table A-1 Testing properties of natural durianwood

Physical properties				Mechanical properties			
Sample / piece (unit)	Density (g/cm ³)	Water absorption (%)	Swelling Coefficient	Hardness (MPa)	Modulus of elasticity (MPa)	Flexure stress (MPa)	Compression (N/mm ²)
1/1	0.55	56.90	0.096	20.20	5860	83.50	44.32
½	0.54	56.31	0.079	21.19	6469	88.70	43.44
1/3	0.54	57.48	0.098	19.06	5825	90.10	63.37
¼	0.53	60.32	0.089	27.45	5215	103.3	49.65
1/5	0.53	61.53	0.079	21.62	5432	81.2	66.81
average.	0.54	58.51	0.088	21.90	5760	89.36	53.52
2/1	0.54	56.39	0.097	21.05	5986	89.20	63.40
2/2	0.57	61.53	0.087	30.58	5827	95.50	48.63
2/3	0.53	57.32	0.085	17.07	6542	87.30	48.36
2/4	0.55	56.55	0.084	22.76	5016	93.50	47.23
2/5	0.55	62.84	0.092	21.33	5128	80.10	50.02
average.	0.55	58.93	0.089	22.56	5700	89.12	51.53
average.	0.55	58.72	0.089	22.23	5730	89.24	52.53
S.D	0.0125	2.54	0.007	3.97	530	7.00	8.60

Table A-2 Testing properties of durianwood-UPR resins Composite A

Physical properties					Mechanical properties						
Sample / piece (unit)	Polymer Loading	Density (g/cm ³)	Water absorption (%)	ASE (%)	Polymer Loading	Hardness (MPa)	Polymer Loading	MOE (MPa)	Flexure stress (MPa)	Polymer Loading	Compression (N/mm ²)
1 / 1	56.24	703.51	21.10	32.58	54.23	30.16	65.91	7907	111.3	53.02	67.04
1 / 2	56.46	760.66	21.32	27.98	56.31	29.40	67.46	8188	109.7	56.69	81.44
1 / 3	59.57	742.20	19.64	24.72	58.42	29.78	67.74	8289	114.7	57.33	85.32
1 / 4	59.64	780.05	17.74	25.84	53.33	31.76	68.21	8263	114.1	58.86	68.29
1 / 5	51.07	710.96	18.80	25.84	52.23	31.15	69.76	8159	112.8	61.58	76.30
Average.	56.60	739.48	19.72	25.39	54.90	30.45	67.82	8161	112.5	57.56	75.68
2 / 1	51.05	772.19	19.72	28.99	53.55	35.59	72.57	7748	116.9	63.16	70.36
2 / 2	51.81	740.00	20.10	25.00	56.23	29.14	64.05	8959	116.6	64.15	78.40
2 / 3	51.90	769.93	19.59	23.46	55.01	36.71	66.90	8082	113.1	64.90	69.42
2 / 4	52.12	741.74	18.87	23.48	56.32	31.13	61.59	8041	120.3	66.67	85.22
2 / 5	56.46	717.61	17.46	20.11	54.23	30.00	66.65	7561	109.4	69.18	67.81
Average.	52.67	748.29	19.15	24.21	55.07	32.51	66.35	8078	115.0	65.61	74.24
average.	54.64	743.89	19.44	24.80	55.00	31.48	67.09	8120	114.0	61.56	74.96
S.D	3.43	26.87	1.27	3.43	1.84	2.61	2.98	375	3.41	5.02	7.29

Table A-3 Testing properties of durianwood-UPR resins Composite B

Physical properties					Mechanical properties						
Sample / piece (unit)	Polymer Loading	Density (g/cm ³)	Water absorption (%)	ASE (%)	Polymer Loading	Hardness (MPa)	Polymer Loading	MOE (MPa)	Flexure stress (MPa)	Polymer Loading	Compression (N/mm ²)
1 / 1	63.80	0.868	10.20	37.08	73.22	41.67	59.89	8026	104.7	75.17	63.80
1 / 2	60.35	0.832	12.23	37.19	74.31	47.08	74.69	8167	114.7	77.98	60.35
1 / 3	62.87	0.856	13.74	30.45	70.23	42.57	67.26	8063	112.6	87.18	62.87
1 / 4	69.62	0.884	8.84	35.50	67.33	44.59	68.43	8026	122.0	92.31	69.62
1 / 5	70.45	0.877	10.10	37.08	67.20	45.51	69.84	8339	117.6	89.38	70.45
Average.	65.42	0.863	11.02	35.46	70.50	44.28	68.02	8134	114.3	84.40	65.42
2 / 1	71.91	0.855	11.23	33.00	69.31	40.18	70.68	8296	122.4	86.16	71.91
2 / 2	72.42	0.817	12.20	36.07	64.32	43.00	72.88	8476	116.0	87.18	72.42
2 / 3	75.47	0.870	14.93	32.58	67.55	47.93	72.91	8151	109.9	88.67	75.47
2 / 4	66.03	0.859	10.59	37.19	68.82	45.32	61.88	8115	111.9	69.02	66.03
2 / 5	69.96	0.910	8.57	35.06	67.73	44.28	80.07	8996	108.2	68.49	69.96
Average.	71.16	0.862	11.50	34.78	67.55	44.14	71.64	8407	113.7	79.90	71.16
average.	68.29	0.863	11.26	35.12	69.02	44.21	69.83	8271	114.0	82.15	68.29
S.D	4.81	0.026	2.04	2.36	2.96	2.40	5.95	297	5.73	8.75	4.81

Table A-4 Testing properties of durianwood-UPR resins Composite C

Physical properties					Mechanical properties						
Sample / piece (unit)	Polymer Loading	Density (g/cm ³)	Water Absorption (%)	ASE (%)	Polymer Loading	Hardness (MPa)	Polymer Loading	MOE (MPa)	Flexure stress (MPa)	Polymer Loading	Compression (N/mm ²)
1 / 1	76.44	0.860	17.21	32.70	73.21	35.98	71.63	12223	187.5	76.04	73.78
1 / 2	67.29	0.840	11.49	39.44	72.42	36.43	60.94	12454	184.3	85.56	79.02
1 / 3	67.80	0.890	8.39	36.18	74.32	38.88	70.90	11558	187.4	79.14	77.04
1 / 4	72.65	0.913	7.44	35.17	70.12	39.48	63.97	10178	152.2	75.45	77.36
1 / 5	69.01	0.840	15.03	31.46	69.32	30.36	64.02	13009	188.8	76.00	68.54
Average.	70.64	0.869	11.91	34.99	71.88	36.23	66.29	11884	180.0	78.44	75.15
2 / 1	67.30	0.830	13.95	33.71	70.32	33.20	66.47	13520	192.7	77.65	75.01
2 / 2	68.24	0.810	13.24	30.21	67.41	35.27	69.06	9595	136.4	81.88	82.27
2 / 3	72.74	0.854	13.59	27.98	69.32	37.63	70.90	11937	192.2	83.12	77.06
2 / 4	75.77	0.850	13.97	44.94	70.12	41.90	71.63	12895	197.4	85.81	83.12
2 / 5	76.93	0.780	12.45	23.60	67.65	40.11	76.47	11189	160.7	72.29	70.44
Average.	72.20	0.825	13.44	32.09	68.96	37.62	70.91	11827	176	80.15	77.58
average.	71.42	0.850	12.68	33.54	70.42	36.93	68.60	11856	178	79.30	76.37
S.D	3.96	0.038	2.94	5.97	2.27	3.44	4.68	1253	20.61	4.61	4.65

Table A-5 Testing properties of durianwood-UPR resins Composite D

Physical properties					Mechanical properties						
Sample / piece (unit)	Polymer Loading	Density (g/cm ³)	Water Absorption (%)	ASE (%)	Polymer Loading	Hardness (MPa)	Polymer Loading	MOE (MPa)	Flexure stress (MPa)	Polymer Loading	Compression (N/mm ²)
1 / 1	64.47	0.849	12.04	37.08	70.22	33.72	70.31	10184	152.3	73.85	72.32
1 / 2	79.72	0.812	13.75	34.72	73.14	29.55	61.22	8887	156.0	78.90	79.61
1 / 3	67.08	0.889	11.84	34.72	68.23	42.77	83.72	9650	153.9	71.07	71.18
1 / 4	68.15	0.848	12.83	39.33	75.66	42.70	69.92	8718	155.3	81.25	76.24
1 / 5	71.48	0.891	12.53	29.21	80.23	35.82	71.64	12537	154.1	73.72	79.74
Average.	70.18	0.858	12.60	35.01	80.23	36.91	71.36	9995	154.32	75.76	75.82
2 / 1	71.85	0.895	12.34	33.01	69.14	34.51	78.75	9084	156.2	79.38	74.32
2 / 2	73.68	0.887	13.20	31.24	67.32	42.65	79.52	10363	161.3	79.87	75.29
2 / 3	76.03	0.865	13.81	32.54	79.50	43.63	65.53	8438	159.4	83.22	79.73
2 / 4	77.93	0.810	14.59	39.21	65.42	31.02	85.71	10068	156.8	87.25	78.38
2 / 5	66.60	0.860	12.69	32.47	69.02	37.62	67.57	9523	151.6	89.40	70.25
Average.	73.22	0.863	13.33	33.69	70.08	37.84	75.42	9495	157.06	83.82	75.59
average.	71.7	0.861	12.97	34.35	71.80	37.40	73.39	9745	155.69	79.79	75.71
S.D	5.14	0.031	0.87	3.35	5.14	5.27	8.12	1177	3.00	6.00	3.64

Table A-6 Testing properties of durianwood-UPR resins Composite E

Physical properties					Mechanical properties						
Sample / piece (unit)	Polymer Loading	Density (g/cm ³)	Water Absorption (%)	ASE (%)	Polymer Loading	Hardness (MPa)	Polymer Loading	MOE (MPa)	Flexure stress (MPa)	Polymer Loading	Compression (N/mm ²)
1 / 1	49.72	0.705	14.15	23.71	53.02	25.17	61.47	7045	103.0	88.97	75.60
1 / 2	57.06	0.758	15.52	26.43	56.33	32.35	69.02	7146	107.7	79.43	78.02
1 / 3	51.92	0.785	13.25	26.97	48.91	32.57	66.83	8010	105.5	76.34	56.81
1 / 4	41.11	0.787	17.05	23.48	48.82	25.10	61.43	6826	102.7	75.17	72.60
1 / 5	46.08	0.760	15.97	31.57	52.02	28.79	65.48	7099	100.9	87.05	76.51
Average.	49.18	0.759	15.19	26.43	51.82	28.80	64.85	7225	103.9	81.40	71.91
2 / 1	50.04	0.728	11.09	29.06	55.33	31.22	66.17	7832	110.8	79.45	53.95
2 / 2	55.05	0.771	14.70	23.82	54.32	29.65	61.40	7980	104.1	77.56	86.56
2 / 3	49.40	0.783	11.89	29.33	46.32	32.00	65.04	7462	106.4	75.34	72.34
2 / 4	54.12	0.724	12.21	30.88	53.92	30.29	60.55	7312	103.2	80.39	84.68
2 / 5	50.14	0.768	12.36	32.34	51.02	31.93	64.35	7297	108.8	72.86	70.19
Average.	51.75	0.755	12.45	27.09	52.18	31.02	63.50	7577	106.7	77.12	73.54
average.	50.47	0.757	13.82	26.76	52.00	29.91	64.18	7401	105.3	79.26	72.73
S.D	4.58	0.028	1.97	3.37	3.21	2.794	2.84	412.03	3.10	51.69	10.53

Table A-7 Testing properties of durianwood-UPR resins Composite F

Physical properties					Mechanical properties						
Sample / piece (unit)	Polymer Loading	Density (g/cm ³)	Water absorption (%)	ASE (%)	Polymer Loading	Hardness (MPa)	Polymer Loading	MOE (MPa)	Flexure stress (MPa)	Polymer Loaading	Compression (N/mm ²)
1 / 1	63.35	0.786	13.07	37.42	60.33	32.28	63.94	9717	108.1	78.98	57.49
1 / 2	65.60	0.780	10.96	39.33	65.32	30.36	61.53	8218	104.5	72.60	75.35
1 / 3	66.31	0.891	15.76	34.04	64.33	44.52	69.31	6955	99.3	78.20	76.79
1 / 4	72.53	0.775	14.70	36.85	59.36	26.88	64.20	8813	105.0	81.37	74.61
1 / 5	60.00	0.760	14.63	32.58	61.23	30.51	65.85	8245	111.6	81.41	75.35
Average.	65.56	0.798	13.83	36.04	62.11	32.91	64.97	8390	105.7	78.51	71.92
2 / 1	69.10	0.821	13.76	35.84	60.33	33.56	66.01	7215	105.3	74.55	78.16
2 / 2	75.28	0.817	10.53	39.33	57.36	33.21	66.90	9716	104.6	81.76	74.85
2 / 3	68.56	0.827	11.92	32.58	60.43	28.73	63.67	7868	111.7	61.33	79.08
2 / 4	60.23	0.810	12.16	36.97	56.32	29.58	63.95	7813	101.8	82.05	75.13
2 / 5	66.31	0.698	15.28	39.33	65.32	21.19	71.15	7204	104.3	88.46	70.01
Average.	67.00	0.795	12.78	36.81	59.95	29.25	66.34	7963	105.5	77.63	75.45
average.	66.73	0.797	13.28	36.43	61.03	31.08	65.66	8176	105.6	78.07	73.69
S.D	4.90	0.06	1.84	2.63	3.12	5.93	2.87	986	3.91	7.32	6.19

Table A-8 Testing properties of durianwood-UPR resins Composite G

Physical properties					Mechanical properties						
Sample / piece (unit)	Polymer Loading	Density (g/cm ³)	Water Absorption (%)	ASE (%)	Polymer Loading	Hardness (MPa)	Polymer Loading	MOE (MPa)	Flexure stress (MPa)	Polymer Loaading	Compression (N/mm ²)
1 / 1	74.22	0.817	6.84	31.67	73.89	33.42	72.13	8939	110.1	80.00	70.25
1 / 2	67.39	0.717	9.74	38.43	74.32	35.60	74.23	9373	118.4	70.06	64.17
1 / 3	72.75	0.925	8.94	36.52	73.23	44.66	73.70	7474	99.4	82.69	76.17
1 / 4	66.60	0.784	7.27	31.80	69.81	30.51	79.65	9226	109.6	83.95	76.09
1 / 5	79.51	0.831	6.65	31.92	70.23	33.74	63.84	9478	116.3	74.34	79.66
Average.	72.09	0.815	7.89	34.27	72.29	35.59	72.71	8898	110.8	78.21	73.27
2 / 1	7.43	0.765	8.76	39.33	71.32	27.45	60.70	9965	113.8	73.75	70.75
2 / 2	76.12	0.925	8.43	32.02	68.00	37.46	72.71	7965	114.3	83.33	73.47
2 / 3	66.22	0.744	8.00	37.42	69.01	26.74	88.50	8255	101.6	83.55	63.65
2 / 4	74.60	0.724	8.19	32.70	65.00	33.06	72.53	8772	118.4	79.30	68.86
2 / 5	75.76	0.799	8.50	39.55	65.32	30.63	71.84	7895	110.6	73.59	82.14
Average.	73.63	0.791	8.38	36.20	67.73	31.06	73.26	8570	111.7	78.70	71.77
average.	72.86	0.803	8.14	35.24	70.01	33.33	72.99	8729	111.3	78.46	72.52
S.D	4.57	0.744	0.97	3.31	3.30	5.21	7.63	808	6.51	5.10	6.15

Table A-9 Testing properties of durianwood-UPR resins Composite H

Physical properties					Mechanical properties						
Sample / piece (unit)	Polymer Loading	Density (g/cm ³)	Water Absorption (%)	ASE (%)	Polymer Loading	Hardness (MPa)	Polymer Loading	MOE (MPa)	Flexure stress (MPa)	Polymer Loading	Compression (N/mm ²)
1 / 1	80.98	0.882	9.67	32.58	76.69	36.12	71.47	6974	98.3	75.09	71.28
1 / 2	75.70	0.893	12.41	32.58	73.65	35.94	79.02	7985	98.4	76.52	74.77
1 / 3	69.95	0.807	14.83	32.47	75.63	33.71	76.83	6306	79.4	77.90	75.03
1 / 4	78.55	0.874	9.59	36.07	74.32	35.08	71.43	7169	101.8	73.44	72.75
1 / 5	72.70	0.890	10.93	39.33	66.44	37.43	75.48	7651	97.9	72.91	72.92
Average.	75.58	0.869	11.55	34.61	73.33	35.66	74.85	7217	95.2	75.17	73.35
2 / 1	68.45	0.820	13.91	46.31	70.75	30.72	76.17	7479	98.8	73.33	77.18
2 / 2	69.39	0.832	12.47	32.36	72.00	31.34	71.40	6323	95.7	66.85	71.83
2 / 3	76.68	0.893	10.47	35.96	71.36	34.13	75.04	7908	103.6	81.60	84.22
2 / 4	77.64	0.863	9.86	32.02	67.98	32.88	70.55	7760	84.9	73.03	75.77
2 / 5	69.73	0.924	9.52	38.31	74.32	34.42	74.35	7180	88.0	70.13	74.03
Average.	72.38	0.866	11.25	37.39	72.31	32.70	73.50	7330	94.2	72.99	76.61
average.	73.98	0.868	11.40	36.00	72.31	34.18	74.18	7274	94.7	74.08	74.98
S.D	4.49	0.037	1.93	5.087	3.27	2.11	2.87	604	7.88	4.08	3.72

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Table A-10 Testing properties of durianwood-UPR resins Composite I

Physical properties					Mechanical properties						
Sample / piece (unit)	Polymer Loading	Density (g/cm ³)	Water absorption (%)	ASE (%)	Polymer Loading	Hardness (MPa)	Polymer Loading	MOE (MPa)	Flexure stress (MPa)	Polymer Loading	Compression (N/mm ²)
1 / 1	67.17	0.853	11.04	31.46	71.23	28.66	74.75	10797	144.6	78.00	74.40
1 / 2	75.55	0.829	11.22	36.07	72.03	26.88	69.30	9494	138.3	79.17	74.03
1 / 3	75.56	0.869	7.29	37.19	75.96	29.08	58.84	8783	134.3	80.69	68.78
1 / 4	68.26	0.855	10.74	35.06	70.02	32.07	69.66	10326	154.2	80.00	62.84
1 / 5	76.50	0.814	10.26	38.20	66.32	28.73	60.06	9017	144.9	79.45	70.52
Average.	72.61	0.844	10.11	35.60	71.11	29.08	66.52	9683	143.3	79.47	70.11
2 / 1	78.71	0.866	13.45	29.33	69.32	28.87	60.71	9656	141.1	82.52	70.69
2 / 2	74.04	0.802	13.44	36.85	67.32	29.16	52.13	8789	145.7	71.83	77.13
2 / 3	75.35	0.809	11.83	29.21	68.53	30.18	69.59	8173	143.7	74.15	64.17
2 / 4	69.93	0.874	11.21	37.42	69.36	28.49	74.07	8753	143.2	75.17	75.15
2 / 5	71.85	0.808	9.94	38.43	70.40	30.90	69.44	9961	146.3	86.62	70.12
Average.	73.98	0.840	11.97	34.25	70.05	29.34	65.19	9066	143.9	78.06	71.45
average.	73.30	0.840	11.04	34.93	70.05	29.21	65.85	9375	143.6	78.79	70.78
S.D	3.81	0.03	1.77	3.58	2.69	1.48	7.43	818	5.25	4.28	4.65

Table A-11 Testing properties of durianwood-UPR resins Composite J

Physical properties					Mechanical properties						
Sample / piece (unit)	Polymer Loading	Density (g/cm ³)	Water absorption (%)	ASE (%)	Polymer Loading	Hardness (MPa)	Polymer Loading	MOE (MPa)	Flexure stress (MPa)	Polymer Loading	Compression (N/mm ²)
1 / 1	75.58	0.888	9.60	35.07	65.32	35.16	57.59	8953	142.2	78.38	63.00
1 / 2	75.96	0.834	8.83	32.58	69.15	32.44	63.67	8450	143.0	84.40	66.67
1 / 3	76.34	0.827	8.96	34.72	70.23	40.21	63.28	9941	155.4	75.66	89.06
1 / 4	73.47	0.844	11.40	34.72	71.36	30.10	62.79	8878	140.7	76.36	80.70
1 / 5	73.10	0.841	9.58	29.21	72.33	35.20	60.47	8911	132.0	78.24	73.62
Average.	74.89	0.847	9.67	35.26	68.43	34.62	61.56	9027	142.7	78.61	74.61
2 / 1	72.66	0.833	9.30	36.97	67.77	38.14	65.13	9587	137.0	71.83	80.21
2 / 2	69.10	0.850	99.94	38.20	65.23	37.03	67.57	8876	150.3	78.91	83.74
2 / 3	62.55	0.862	8.02	34.61	61.42	35.12	61.67	8353	144.5	83.80	76.75
2 / 4	77.52	0.834	9.42	33.60	74.51	32.18	66.03	8998	141.7	70.95	73.41
2 / 5	69.88	0.875	7.30	35.90	73.21	35.66	63.43	11937	138.1	76.06	75.00
Average.	70.34	0.851	8.80	35.86	69.68	35.12	64.77	9550	142.3	76.31	77.82
average.	72.62	0.849	9.24	35.56	69.05	35.12	63.17	9288	142.5	77.46	76.22
S.D	4.47	0.020	1.10	2.46	4.12	2.98	2.84	1043	6.63	4.38	7.74

Table A-12 Testing properties of durianwood-UPR resins Composite K

Physical properties					Mechanical properties						
Sample / piece (unit)	Polymer Loading	Density (g/cm ³)	Water Absorption (%)	ASE (%)	Polymer Loading	Hardness (MPa)	Polymer Loading	MOE (MPa)	Flexure stress (MPa)	Polymer Loading	Compression (N/mm ²)
1 / 1	69.96	0.856	15.35	39.33	74.56	36.05	72.89	10671	149.7	69.96	85.07
1 / 2	77.58	0.863	14.85	43.55	75.63	30.01	67.75	8448	143.1	67.58	74.42
1 / 3	78.87	0.824	10.23	39.44	76.60	32.71	74.92	10052	144.7	69.87	83.44
1 / 4	72.43	0.855	11.37	31.46	68.32	28.80	68.01	8576	139.7	72.43	80.09
1 / 5	69.96	0.861	11.96	38.09	69.32	31.43	73.44	8678	139.4	69.96	76.79
Average.	73.76	0.839	12.75	38.37	72.89	31.80	71.40	9685	143.3	69.96	79.96
2 / 1	63.94	0.859	13.78	38.31	74.00	36.76	75.74	8185	141.8	73.94	76.69
2 / 2	78.61	0.885	11.58	41.46	73.96	33.85	64.98	9831	147.5	68.61	84.04
2 / 3	74.43	0.855	12.74	36.12	71.13	29.58	71.48	9179	141.9	74.43	76.60
2 / 4	73.20	0.870	12.11	35.32	70.56	36.34	68.25	8286	143.4	73.26	83.60
2 / 5	77.14	0.857	15.02	41.39	71.23	27.88	67.23	10305	139.2	77.14	80.35
Average.	73.46	0.847	13.05	38.54	72.53	32.88	69.54	9157	142.8	73.48	80.26
average.	73.61	0.859	12.90	38.46	72.53	32.44	70.47	9421	143.0	71.72	80.11
S.D	4.75	0.015	1.76	3.49	2.79	3.30	3.69	919	3.48	3.00	3.81

Table A-13 Testing properties of durianwood-UPR resins Composite L

Physical properties					Mechanical properties						
Sample / piece (unit)	Polymer Loading	Density (g/cm ³)	Water absorption (%)	ASE (%)	Polymer Loading	Hardness (MPa)	Polymer Loading	MOE (MPa)	Flexure stress (MPa)	Polymer Loading	Compression (N/mm ²)
1 / 1	50.76	0.749	9.00	31.90	52.89	37.40	61.33	11023	150.0	72.73	50.30
1 / 2	45.50	0.774	9.45	28.31	51.63	34.84	64.91	8963	139.6	76.81	46.49
1 / 3	42.33	0.723	11.10	27.08	48.96	38.07	60.37	12030	142.3	74.36	55.03
1 / 4	65.47	0.717	10.82	34.00	55.23	30.85	67.80	9560	139.0	77.24	56.35
1 / 5	48.84	0.795	11.12	32.70	46.32	31.84	56.95	8523	136.2	76.56	62.11
Average.	50.58	0.752	10.30	30.80	51.01	35.60	62.27	10019	141.4	75.54	54.06
2 / 1	50.99	0.739	9.34	36.85	53.26	39.54	60.57	11423	145.6	74.47	53.75
2 / 2	51.03	0.807	10.50	33.82	50.32	37.69	61.35	8703	142.3	74.32	56.59
2 / 3	63.26	0.750	9.76	32.69	56.32	32.14	58.71	8450	145.6	76.26	56.07
2 / 4	48.48	0.809	11.62	27.08	57.61	32.77	64.55	8432	138.2	75.17	65.74
2 / 5	65.57	0.750	14.39	28.43	47.63	34.99	60.76	8023	136.5	72.41	54.61
Average.	55.82	0.771	11.12	21.77	53.03	35.43	61.19	9006	141.7	74.33	57.35
average.	53.23	0.762	10.71	31.29	52.01	35.52	61.73	9513	141.5	75.03	55.71
S.D	8.43	0.033	1.57	3.36	3.75	2.87	3.19	1442	4.48	1.68	5.40

Table A-14 Testing properties of durianwood-UPR resins Composite M

Physical properties					Mechanical properties						
Sample / piece (unit)	Polymer Loading	Density (g/cm ³)	Water Absorption (%)	ASE (%)	Polymer Loading	Hardness (MPa)	Polymer Loading	MOE (MPa)	Flexure stress (MPa)	Polymer Loading	Compression (N/mm ²)
1 / 1	72.99	0.817	7.7	36.07	75.61	34.16	68.66	9600	162.3	79.96	81.13
1 / 2	71.81	0.817	10.31	37.08	73.31	40.39	72.88	10320	156.3	79.23	79.20
1 / 3	73.83	0.808	9.94	29.21	74.51	36.05	73.92	8456	160.4	73.51	84.79
1 / 4	67.69	0.811	10.01	31.24	74.60	30.23	77.47	10023	154.3	78.63	80.20
1 / 5	74.04	0.815	9.73	35.06	76.32	34.29	71.96	9550	165.0	83.62	82.04
Average.	72.07	0.814	9.54	33.73	74.88	35.02	72.98	9590	159.7	78.99	81.47
2 / 1	75.52	0.808	9.25	38.31	68.91	30.20	73.73	10499	160.0	70.06	77.24
2 / 2	74.43	0.822	11.31	38.20	74.12	37.12	77.84	11230	159.0	80.62	76.68
2 / 3	67.89	0.859	12.24	33.48	67.67	31.63	70.35	13520	160.1	83.69	80.85
2 / 4	73.30	0.865	10.33	37.98	70.12	31.06	65.89	11150	160.2	80.51	79.12
2 / 5	74.25	0.849	9.29	34.94	75.61	35.63	68.04	11265	153.2	75.17	74.45
Average.	73.08	0.827	10.48	36.58	71.29	33.13	71.17	11533	158.5	78.01	77.67
average.	72.58	0.827	10.01	35.16	73.08	34.08	72.08	10561	159.1	78.50	79.57
S.D	2.70	0.022	1.21	3.08	3.06	3.34	3.92	1365	3.58	4.37	2.95

Table A-15 Testing properties of durianwood-UPR resins Composite N

Physical properties					Mechanical properties						
Sample / piece (unit)	Polymer Loading	Density (g/cm ³)	Water Absorption (%)	ASE (%)	Polymer Loading	Hardness (MPa)	Polymer Loading	MOE (MPa)	Flexure stress (MPa)	Polymer Loading	Compression (N/mm ²)
1 / 1	74.09	0.866	12.20	36.85	74.70	27.16	66.92	11820	160.9	77.59	74.13
1 / 2	72.37	0.876	12.08	31.46	76.32	35.13	76.77	9971	156.0	88.28	74.46
1 / 3	78.50	0.786	10.40	36.07	75.61	33.04	69.10	10274	158.5	79.57	73.23
1 / 4	75.71	0.870	11.87	30.34	68.91	30.86	69.67	11471	169.5	74.49	65.09
1 / 5	69.45	0.847	11.75	38.43	75.23	33.42	74.51	10282	164.8	78.09	71.13
Average.	74.02	0.849	11.66	34.63	74.15	31.92	71.39	10764	161.9	79.60	71.61
2 / 1	75.66	0.899	10.49	36.85	72.30	29.68	72.88	8563	162.5	87.36	72.91
2 / 2	75.57	0.835	10.25	38.20	69.47	30.15	72.53	9048	167.3	77.66	72.57
2 / 3	67.96	0.842	12.65	34.94	69.13	39.68	65.29	11642	167.4	86.32	69.36
2 / 4	66.14	0.802	11.46	36.97	76.31	36.12	69.66	12460	158.7	73.56	73.44
2 / 5	67.50	0.877	13.87	35.73	77.96	29.87	79.73	10047	160.7	80.23	69.23
Average.	72.50	0.869	11.74	36.54	73.03	33.08	72.02	10352	163.3	81.03	71.48
average.	73.26	0.859	11.70	35.59	73.59	32.50	71.71	10558	162.6	80.32	71.55
S.D	4.26	0.033	1.12	2.69	3.37	3.73	4.46	1258	4.47	5.26	2.92

Table A-16 Testing properties of durianwood-UPR resins Composite O

Physical properties					Mechanical properties						
Sample / piece (unit)	Polymer Loading	Density (g/cm ³)	Water absorption (%)	ASE (%)	Polymer Loading	Hardness (MPa)	Polymer Loading	MOE (MPa)	Flexure stress (MPa)	Polymer Loaading	Compression (N/mm ²)
1 / 1	63.18	0.822	8.24	40.56	50.23	36.00	50.90	9245	132.1	61.88	65.47
1 / 2	59.06	0.806	10.50	37.21	51.36	38.19	51.46	11156	130.9	66.43	63.13
1 / 3	53.93	0.778	12.24	39.33	55.62	32.55	51.81	9606	134.0	67.30	68.73
1 / 4	59.50	0.791	10.68	37.98	54.32	42.81	55.27	8946	131.6	69.06	64.90
1 / 5	59.77	0.859	14.29	32.98	57.75	34.52	48.75	7099	134.9	65.93	59.97
Average.	59.09	0.811	11.19	37.51	53.86	36.81	51.64	9210	132.7	66.12	64.44
2 / 1	55.42	0.787	12.03	40.56	48.21	36.23	50.90	9340	127.8	61.34	66.54
2 / 2	52.79	0.803	11.53	38.31	50.12	39.02	55.20	9455	136.0	69.92	59.11
2 / 3	58.24	0.789	9.50	32.47	54.23	42.00	51.98	8806	134.7	68.97	68.03
2 / 4	57.24	0.884	10.15	41.35	46.78	33.21	49.57	9317	140.0	73.58	63.96
2 / 5	54.33	0.780	8.91	30.34	51.88	31.08	51.59	9033	127.9	68.8	73.21
Average.	55.60	0.809	10.42	36.61	50.55	36.31	51.85	9190	133.28	68.42	66.17
average.	57.35	0.810	10.81	37.06	52.05	36.56	51.75	9200	132.99	67.27	65.31
S.D	3.22	0.035	1.78	3.91	3.24	3.93	2.10	2289	3.74	3.66	4.17

Table A-17 Testing properties of durianwood-UPR resins Composite P

Physical properties					Mechanical properties						
Sample / piece (unit)	Polymer Loading	Density (g/cm ³)	Water Absorption (%)	ASE (%)	Polymer Loading	Hardness (MPa)	Polymer Loading	MOE (MPa)	Flexure stress (MPa)	Polymer Loading	Compression (N/mm ²)
1 / 1	97.62	0.889	7.78	54.04	78.31	48.00	80.90	12047	180.9	78.26	76.76
1 / 2	78.89	0.758	10.43	51.69	79.54	38.19	71.46	12471	179.3	95.45	79.63
1 / 3 ✓	91.02	0.860	6.60	54.04	76.32	38.55	71.81	12535	175.1	85.14	79.66
1 / 4	95.85	0.809	8.04	49.44	74.48	42.81	75.27	13114	192.3	82.76	74.11
1 / 5	91.02	0.842	9.04	52.70	74.16	41.17	68.75	11914	173.4	91.91	76.35
Average.	90.88	0.832	8.38	52.38	76.56	41.74	73.64	12416	180.2	86.70	77.30
2 / 1	94.71	0.840	6.83	54.16	79.35	51.84	70.90	12747	184.5	92.41	75.73
2 / 2	95.60	0.894	8.36	51.57	80.00	44.09	75.20	9547	178.1	80.00	71.63
2 / 3	82.17	0.783	9.09	56.18	75.00	48.00	71.48	12773	181.0	99.26	80.00
2 / 4	91.98	0.879	6.16	42.70	75.23	33.21	79.57	11327	179.2	85.50	71.81
2 / 5	94.37	0.856	7.14	46.07	74.15	31.08	71.59	9423	178.5	96.43	73.38
Average.	91.77	0.850	7.52	50.14	76.75	41.64	73.81	11163	180.3	90.72	74.51
average. ✓	91.33	0.841	7.95	51.26	76.65	41.69	73.73	11790	180.3	88.71	75.90
S.D	6.11	45.22	1.32	4.14	2.40	6.64	3.95	1316	5.24	7.33	3.17

Table A-18 Testing properties of durianwood-UPR resins Composite Q

Physical properties					Mechanical properties						
Sample / piece (unit)	Polymer Loading	Density (g/cm ³)	Water Absorption (%)	ASE (%)	Polymer Loading	Hardness (MPa)	Polymer Loading	MOE (MPa)	Flexure stress (MPa)	Polymer Loading	Compression (N/mm ²)
1 / 1	100.59	0.822	6.50	60.67	80.63	44.63	80.49	10576	163.9	82.39	91.30
1 / 2	97.36	0.830	6.04	43.50	82.31	36.60	86.35	10126	159.9	87.92	94.51
1 / 3	97.97	0.857	8.84	64.04	85.34	35.53	60.52	11753	146.9	87.50	83.28
1 / 4	93.86	0.847	7.09	48.31	86.21	42.65	86.21	10929	167.7	84.72	90.03
1 / 5	100.86	0.862	6.16	61.80	89.41	45.62	69.01	10138	147.8	78.10	83.07
Average.	98.13	0.844	6.93	55.66	84.78	41.00	76.52	10704	157.2	84.13	88.44
2 / 1	101.73	0.820	6.45	49.33	87.41	35.74	68.35	10231	153.4	97.73	87.77
2 / 2	102.29	0.843	6.85	48.20	84.98	39.94	79.38	10441	164.1	84.73	77.70
2 / 3	99.79	0.839	6.26	50.11	88.21	42.70	71.20	11731	164.9	90.30	84.07
2 / 4	101.59	0.870	6.88	52.81	80.21	39.47	67.90	9217	149.8	86.39	82.50
2 / 5	98.98	0.843	8.69	45.96	87.40	38.02	80.54	10107	151.1	78.42	80.56
Average.	100.88	0.843	7.02	49.28	85.64	40.09	73.47	10345	156.7	87.51	82.92
Average.	100.05	0.844	6.98	52.47	85.21	40.09	75.00	10525	156.9	85.82	85.68
S.D	2.57	0.017	1.00	7.17	3.19	3.67	8.75	776	7.96	5.75	5.07

VITA

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