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**PHYSICAL AND MECHANICAL PROPERTIES OF RUBBERWOOD-POLY
(STYRENE-CO-BUTYLACRYLATE) AND POLY(STYRENE-CO-
ACRYLAMIDE) COMPOSITES**



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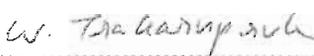
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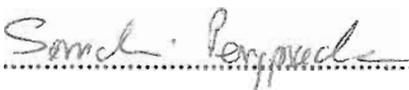
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งานวิจัยนี้เป็นการเตรียมไม้ยางพารา-พอลิ(สไตรีน-โค-บิวทิลอะคริเลต) และพอลิ(สไตรีน-โค-อะคริลาไมด์)คอมโพสิตด้วยวิธีอิมเพกเนชันไม้ยางพาราด้วยมอนอเมอร์ผสม โดยศึกษาผลของชนิดของตัวริเริ่มปฏิกิริยา ปริมาณของตัวริเริ่มปฏิกิริยาที่มีผลต่อความหนืด และอัตราส่วนของโมโนเมอร์ รวมทั้งศึกษาสถานะที่เหมาะสมในกระบวนการเตรียมตัวอย่าง เช่น เวลาที่ใช้ในการดึงอากาศออกจากช่องว่างในเซลไม้ เวลาที่ใช้แช่ขึ้นตัวอย่างในส่วนผสม โดยแปรเปลี่ยนค่าเหล่านั้นให้แตกต่างกันในการเตรียมแต่ละตัวอย่าง และศึกษาผลกระทบที่มีต่อสมบัติความเสถียรทางกายภาพและสมบัติเชิงกลของตัวอย่างที่เตรียมขึ้น เปรียบเทียบกับไม้ยางพาราธรรมชาติ

ผลการศึกษาพบว่าเบนโซอิลเปอร์ออกไซด์ 2 ส่วนต่อของผสมมอนอเมอร์ 100 ส่วนมีความเหมาะสมในการใช้เตรียมตัวอย่าง และสถานะที่เหมาะสมในกระบวนการเตรียมตัวอย่างเป็นดังนี้ คือ เวลาที่ใช้ในการดึงอากาศออกจากช่องว่างในเซลไม้ 2 ชั่วโมง และเวลาที่ใช้ในการแช่ขึ้นตัวอย่าง 4 ชั่วโมง ซึ่งตัวอย่างไม้ยางพารา-พอลิ(สไตรีน-โค-บิวทิลอะคริเลต)และพอลิ(สไตรีน-โค-อะคริลาไมด์)คอมโพสิตที่เตรียมขึ้นจากสถานะดังกล่าวมีสมบัติความเสถียรทางขนาดคือ ค่าการดูดซึมน้ำประมาณ 18-34% ซึ่งต่ำกว่าไม้ยางพาราธรรมชาติ และสมบัติเชิงกลคือ ค่ามอดุลัสยืดหยุ่นประมาณ 7951-10165 เมกกะปาสคาล ความทนแรงบิดงอประมาณ 115-159 เมกกะปาสคาล การทนแรงอัดประมาณ 67-90 เมกกะปาสคาลซึ่งสมบัติเหล่านี้สูงกว่าไม้ยางพาราธรรมชาติ

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AUSANA SUKHONPHANICH : PHYSICAL AND MECHANICAL PROPERTIES OF RUBBERWOOD-POLY(STYRENE-CO-BUTYLACRYLATE) AND POLY(STYRENE-CO-ACRYLAMIDE) COMPOSITES. THESIS ADVISOR : ASSOC. PROF. AMORN PETSOM, Ph.D. 96 pp. ISBN 974-13-1215-6

This research involves the preparation of para rubberwood-poly(styrene-co-butylacrylate) and poly(styrene-co-acrylamide) composites by impregnation of rubberwood with mixture of monomers. The effects of initiator types, initiator content that related to viscosity and monomer ratio were studied. Impregnation parameters such as evacuating time, soaking time were varied to various conditions in preparation processes. Physical and mechanical properties of impregnated samples were compared with those of natural para rubberwood.

Results of this study showed that 2 phr. benzoyl peroxide in monomer mixture was suitable to prepare wood-polymer composites. The optimum preparation parameters were 2 hours evacuating time, and 4 hours soaking time. The rubberwood-poly(styrene-co-butylacrylate) and poly(styrene-co-acrylamide) obtained from the optimum conditions gave 18-34% of water absorption which was lower than that of natural para rubberwood. Mechanical properties such as modulus of elasticity, flexure stress, compression parallel to grain were at about 7951-10165 MPa, 115-159 MPa, 67-90 MPa, respectively, which were higher than those of natural para rubberwood.

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LIST OF ABBREVIATIONS

WPC	-	Wood-polymer composite
ST	-	Styrene
MMA	-	Methyl methacrylate
PEG	-	Poly(ethylene glycol)
BA	-	Butylacrylate
AM	-	Acrylamide
PL	-	Polymer loading
ASE	-	Antiswell efficiency
BPO	-	Benzoyl peroxide
MEKPO	-	Methyl ethyl ketone peroxide
WA	-	Water absorption
S	-	Volumetric swelling coefficient
MEO	-	Modulus of elasticity
SEM	-	Scanning electron microscopy
phr	-	Part per hundred resin
°C	-	Degree Celsius
MC	-	Moisture content
Mpa	-	Mega pascal
N/mm ²	-	Newton per square millimeter

CHAPTER I



INTRODUCTION

Wood and other products derived from tree have been important in the human economy since earliest times. In modern industrial societies wood is a major material of construction such as homes, furniture, bridges, poles and railroad ties. Wood yields fiber for pulp, paper, and fiberboard and provides material for plywood, particleboard, and pallets and also for the valuable textile, rayon. In many localities wood serves as a fuel. It is a source of important industrial chemicals.[1,2]

Wood is used in various areas because of many desirable properties such as high specific strength, low heat conductivity, electric insulation, ability of controlling atmospheric humidity, beautiful appearance, and so on. However, wood also has undesirable properties. Those undesirable properties are; wood swells and shrinks with changing moisture contents; wood is biologically degraded by microorganism; wood undergoes flaming combustion with increasing temperature; wood is degraded by action of acids and bases; and wood is photochemically degraded by ultraviolet light. Therefore, the chemical modification of wood can improve these undesirable properties.

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., and from erosion from salinity, attacks by

microbes, insects, and moisture absorption. In a real sense, modification of various physical and mechanical properties of wood and its products by chemical treatment started in the 1930s. [3]

Rubberwood is the timber of *Hevea brasiliensis*. "RUBBER TREE" as it is popularly known. The value of the rubber tree till recently has been mainly for its latex. But this is slowly changing. The utilization of the rubber tree in a holistic sense is now being given focus: for instance, the tree is being looked at from the environment angle: plant nutrients and other useful chemicals are being sourced from effluents and waste from rubber processing and above all rubber timber is now a valuable resource.

The good working qualities of rubberwood, its durability, pleasant appearance and beautiful grains make it suitable for numerous end uses. It is an ideal wood for making furniture, from household furniture to padded or upholstered furniture. Rubberwood in solid or laminated form is used in manufacturing of moldings, parquet, household utility items, toys and many other finished items. It is also used for making plywood, particle board, layered construction materials, fibre board, wood cement board, composite woods, paper, charcoal, etc. Moreover, rubberwood is still an important source of fuel in many areas.[4] Rubber trees are shown in Figure 1.1

Rubberwood, despite its valuable properties, is known to display undesirable properties, such as low durability and resistance to insect. Thus, the purpose of this research was to add the economic value by improving physical and mechanical properties to rubberwood.



Figure 1.1 Rubber trees [5]

1.1 Objectives of the research work

1. To prepare the para rubberwood poly(styrene-co-butylacrylate) and poly(styrene-co-acrylamide) composites.
2. To study physical and mechanical properties of para rubberwood poly(styrene-co-butylacrylate) and poly(styrene-co-acrylamide) composites obtained under various conditions.

1.2 Scopes of the research work

In this research work, the wood-polymer composites was prepared from poly(styrene-co-butylacrylate) and poly(styrene-co-acrylamide) and para rubberwood by impregnation. Suitable copolymer mixture and various impregnation conditions such as soaking time, concentrated initiator and monomer ratio were investigated. The physical and mechanical properties of specimens such as polymer loading, water absorption, flexure stress, modulus of elasticity, antishrink efficiency, compression parallel to grain, termite resistance and SEM of microstructure figures were studied.

CHAPTER II

THEORY AND LITERATURE REVIEW

Treatment of wood to improve its physical and mechanical properties and dimensional stabilization due to moisture content and impart resistance to termites, decay, and marine organisms has been carried out via chemical modification or chemical impregnation. In chemical modification, compound highly reactive to the hydroxyl groups of cellulose, hemicellulose, and lignin components of wood includes isocyanates, epoxides, anhydrides, lactones, and diols. Several liquid monomers such as styrene (ST) and methyl methacrylate (MMA) were also incorporated into wood samples by means of chemical impregnation. Crosslinking of wood material in wood samples provides good dimensional stability to the wood-polymer composite.[6]

2.1 Definition of wood-polymer composites

Wood-polymer composite (WPC) is a wood impregnated with polymers in order to strengthen the properties of the natural wood. In the broad sense, WPC includes the composite, that is made by impregnating wood with a phenol-, a urea-, or a melamine-formaldehyde prepolymer. Then, the prepolymer is cured 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, ect.) 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

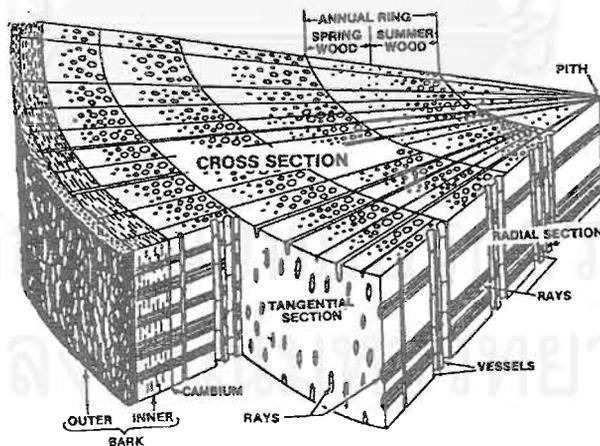
polymerizing them to a solid.[7]

2.2 Formation and structure of wood

2.2.1 Anatomy of wood

Wood is a natural product composed of a highly polymerized carbohydrate (cellulose, 50-60%), lignin (25%), solid material (24%), gums, resins, and so on, with 1% ash. The chemical compounds may vary with the types of trees and growing conditions. These materials are arranged in walls of tubular structures called cells, which may have different shapes and structures, according to their required functions, and are systematically ordered into tissues that are cylindrical along the surface of the stem. The entire arrangement produces a mass of radial symmetry-three axes of major orientations with respect to the stem; these are longitudinal, tangential, and radial. It also gives a complex anisotropy of elongated polymer molecules of the cellulose.[3]

Figure 2.1 Cross sectional detail of a log [8]



Between the bark and the wood itself in Figure 2.1 is a layer of thin, living cells, called cambium. In the cambium the growth in thickness of the bark and the wood develops by cell division. Wood that is already formed does not grow either in diameter or in length. New growth always takes place by the addition of new cells at

the cambium, mostly in the spring and summer months in the temperate zones. It is this seasonal growth that produces well-marked annual growth rings.

Growth rings in trees are made up of springwood and summerwood. The portion formed early in the growing season is called springwood (early wood) and that is formed later is called summerwood (late wood). Springwood is very different from the summerwood. It is lighter in weight, softer, and weaker than summerwood. Springwood shrinks less across the grain and more lengthwise along the grain.[8]

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 angle to the growth rings.

Woods are divided into two classes: hardwoods and softwoods. 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 turned longitudinal tracheids which perform a dual role of conduction and support. The term hardwood and softwood 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.

จุฬาลงกรณ์มหาวิทยาลัย

2.2.2 Hardwood [9]

The hardwoods (Figure 2.2) are heterogeneous in their structure, having a greater complexity of cell form, 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 to the rays and also of the wood parenchyma cells, which are quite well developed in some species.

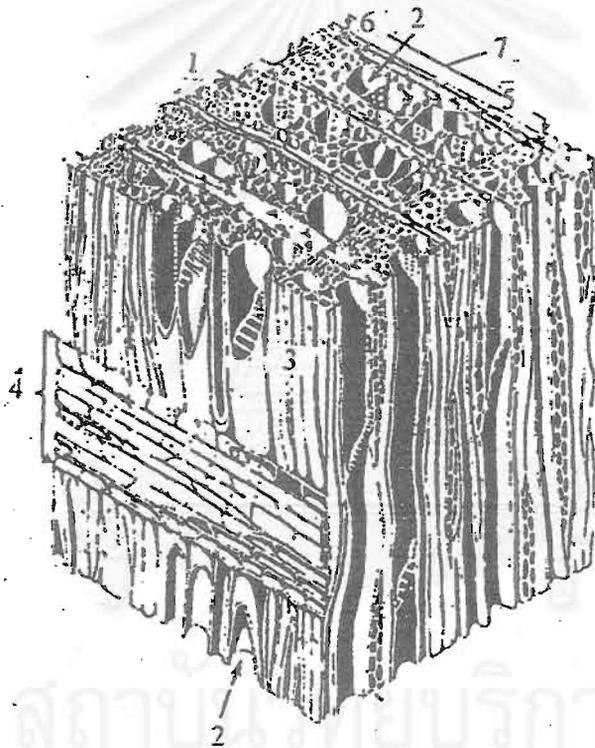


Figure 2.2 Magnified three dimensional diagrammatic sketch of a hardwood:

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

2.2.2 Softwood [9]

The softwoods (Figure 2.3) are comparatively homogeneous, consisting essentially of two main elements or cell forms: tracheids and rays. Tracheids concern in the living tree with the dual function of sap conduction and mechanical support. And, rays 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.

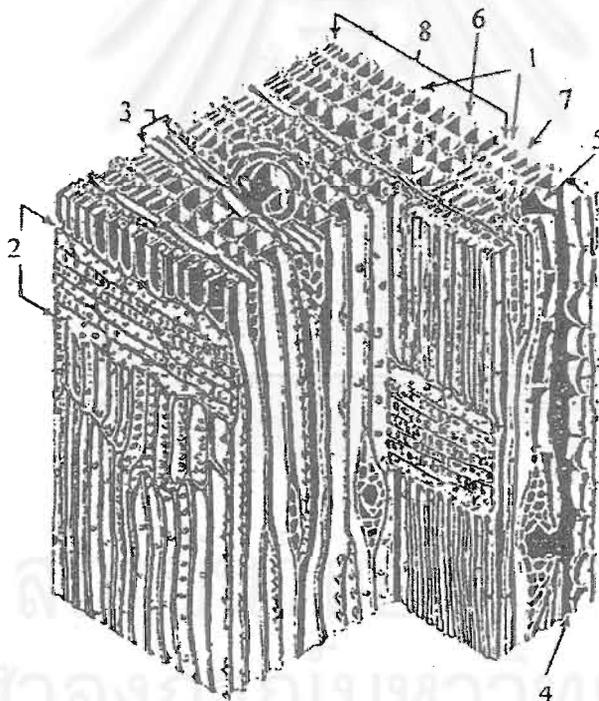


Figure 2.3 Magnified three- dimensional diagrammatic sketch of softwood:

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

2.3 Rubberwood

2.3.1 Anatomy of rubberwood [10]

The texture of the wood is fairly even with moderately straight and slightly interlocking grain. It is whitish yellow when freshly cut, but the wood turns to light brown drying. Latex vessels can be found with characteristic smell in some parts of the wood. The wood is soft to moderately hard with an average weight of 515 kilograms per cubic meters at 12% moisture content. Pores on the cross section are diffused and of medium to large size, mostly solitary but sometimes in short multiples of two to three, filled with tyloses. Vessel tissues are conspicuous in radial and tangential faces and are of the order of about 200 micron in diameter. Wood parenchyma are abundantly visible to the naked eye appearing as narrow, irregular and somewhat closely spaced bands forming a net like pattern with rays. The rays of the wood are moderately broad, rather few and fairly wide spread. The pits found between the vessels and rays are haft-bordered with narrow width. The length of the fibres is more than 1.0 millimeters on the average and the width is about 22 microns when dry. The cell wall thickness when dry is about 2.8 microns.

There is insignificant heart wood formation and no transition appears between sapwood and heart wood, which is confined near the pith. Growth rings or annual rings are not visible in rubber wood, unlike many other wood (ring porous woods). However, concentric false rings sometimes appear on the wood, depending on the presence of tension wood (gelatinous cells) which are fairly common in most of the clones. Maximum number of such rings are found in the basal portions with decreasing number towards the top. The tension wood may vary from 15 to 65 % and such erratic distribution tends to give a woolly appearance on the surface of wood. Such distribution and variation are supposed to be responsible for some of the commonly observed defects that may occur during drying and processing. The other characteristics of rubber wood are summarised in Table 2.1

Table 2.1 Properties of rubber tree bark wood elements

Basic wood density (kg m ⁻³)	543.7
Basic bark density (kg m ⁻³)	620.8
Double bark thickness (mm)	11.6
Bark proportion (%)	7.7
Fibre length (mm)	1.189
Fibre proportion (%)	58.0
Vessel proportion (%)	8.5
Ray proportion (%)	22.0
Parenchyma (%)	11.5

2.3.2 Physical and Mechanical Properties

Rubberwood, like most woods, exhibits orthotropicity properties. Its properties are different and independent in the three principal directions of growth: longitudinal, radial and tangential. Being nonhomogeneous in its structure, its density also varies from site to site inside the material. The variations in properties are attributable not only to the variations in density but also to the presence of latex particles in some locations and to the predominance of tension wood.

Edaphic, agrometeorological and plant factors such as elevation, air temperature, solar radiation, humidity, rainfall, soil characteristics, spacing, clonal difference and age of the tree can influence to a certain degree the properties of any species of wood. However, these changes may be significant with reference to the expected end use and are generally taken care of in the system of evaluation itself by drawing samples representative of different growth conditions. However, it should be noted that strength, in the green condition does not vary with moisture content.

Like most wood species, the dynamic properties of rubber wood are higher than the static properties. For instance, under impact loads, rubberwood is capable of taking loads nearly twice that under slowly loads. However, it may be noted that the static properties of rubberwood in dry condition are higher than those in green condition. But in the case of dynamic properties, the reverse is the case for fiber stress at elastic limit and modulus of elasticity and the increase is not significant in the case of maximum height of drop. This shown that in such cases where shocks come into play, presence of moisture in wood is helpful in taking up higher loads.

2.4 Monomer treatments

Representative types of monomers and prepolymers have been used to make wood-polymer composites (WPC) during the past 30 years. The most widely used industrial monomers, such as methyl methacrylate (MMA) and styrene (ST) are the cheapest WPC base chemicals and are easy for engineering. The lower the viscosity of monomer is the easier the impregnation becomes. To a monomer solution, soluble, light-stable dyes can be added to color the final WPC. The color emphasizes the grain structure of the particular species. The third component, chemicals such as a crosslinker, an absorbent of ultraviolet rays, a flame retardant, and preservatives can be added to improve the properties of WPC and the organic solvent for swelling the cell wall to control the impregnation area of monomers.[7]

2.4.1 Styrene

Styrene is prepared from 1-phenylethanol. An outstanding characteristic of styrene monomer is its ability to be polymerized readily by a variety of methods and with a large variety of other monomers. Styrene monomer is successfully polymerized and copolymerized by both batch and continuous mass polymerization, and emulsion processes, as well as by various modifications and combinations of these techniques. Styrene responds to a large number of initiators such as peroxides and other free radical initiators, redox initiator systems, ionic initiators, and others. Styrene is

copolymerized to form commercial copolymers with the acrylates and methacrylates, acrylonitrile, butadiene, divinylbenzene, maleic anhydride, and others. Styrene is used in manufacturing plastic such as synthetic rubber, resins, and insulator. [11]

Physical properties of polystyrene are water-clear solid plastic having excellent insulating properties even at ultra-high radio frequencies, begins to soften at about 85°C and dielectric constant at 100 megacycle is 2.40-2.65.

2.4.2 Butylacrylate

Butylacrylate is prepared from butyl alcohol and methylacrylate. The monomer of butylacrylate is used in the manufacture of acrylate polymers and resins for textile and leather finishes. It is also used in paint formulations. Butylacrylate is found to be moderately irritating to the skin, and as an eye irritant, produced corneal necrosis in the unwashed rabbit eye similar to that produced by ethyl alcohol.

Physical properties of polybutylacrylate is a clear plastic and dielectric constant at 100 megacycle is 3.20-3.50. Polybutylacrylate have elastic and tacky substance.

2.4.3 Acrylamide

Acrylamide is a white, crystalline solid and prepared from acrylonitrile by treatment with sulfuric acid or hydrochloric acid. Acrylamide polymerizes easily in the presence of free radical initiators to form chains of the structure. And, it copolymerizes easily with many vinyl monomers. Reaction rates and molecular weights tend to be lower than those obtained from acrylamide homopolymerization. The acrylamide content of copolymers is often higher than that of the feed. Some of the most widely used comonomers are weak acids, strong acid, and bases.

Physical properties of polyacrylamide such as density at 23°C, glass transition temperature, critical surface tension are 1.302 g/cm³, 153°C and 30-40 mN/m, respectively.[12]

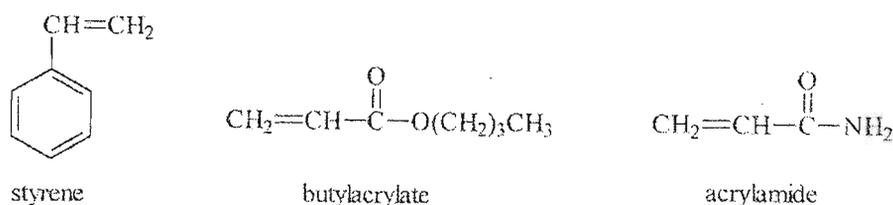


Figure 2.4 Chemical structures of styrene, butylacrylate and acrylamide

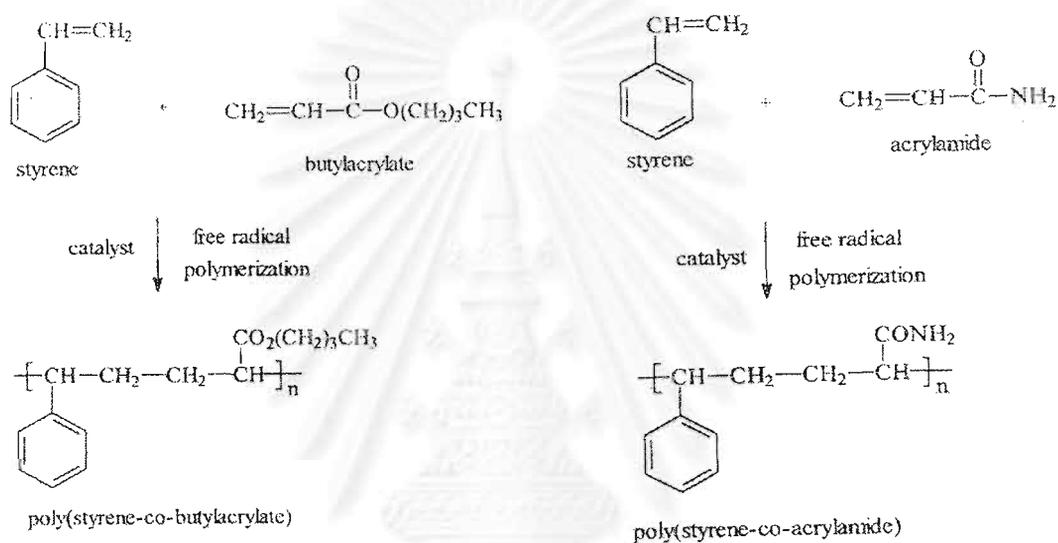


Figure 2.5 Preparation of poly(styrene-co-butylacrylate) and poly(styrene-co-acrylamide)

2.4.4 Initiator

Peroxide initiators are chemical substances that possess one or more oxygen-oxygen bonds. Their general structures are ROOR^1 or ROOH where R and R^1 are inorganic or organic groups. Under the influence of heat or light, the weak oxygen-oxygen bond cleaves to produce a pair of free radicals.[13]

2.5 Impregnation Process [7,14]

This process is operated by batch system in the sealed vessel. The monomers may be introduced as a liquid-phase or as a gas-phase, but in the industry the former process is preferred. After the woods are placed in a vessel, air is first evacuated from the vessel and wood cell lumen. Then, the monomers are introduced into the vessel under the vacuum. The monomer loading is controlled under reduced and atmospheric pressure or reduced and air or nitrogen pressure. This operation is similar to the preservatives for wood, but differs only in using the nonaqueous and reactive monomer solution. The amount of monomer loading depending upon the monomer composition, the period of impregnation, and the structure and species of wood. The apparatus of impregnation are shown in Figure 2.4

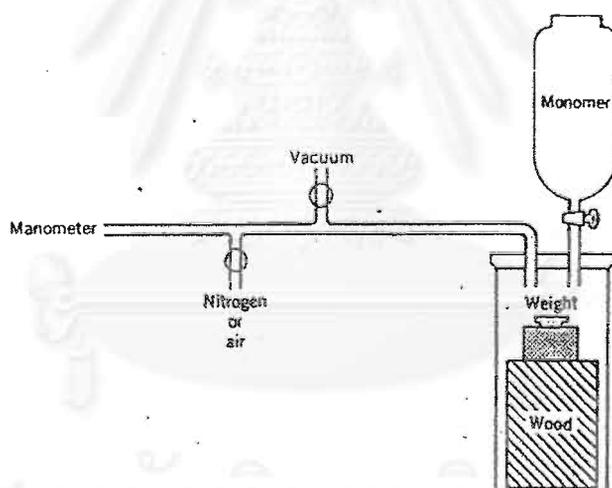


Figure 2.6 The apparatus of impregnation process [14]

2.6 Polymerization

Polymerization of monomers or prepolymers can be initiated using ionizing radiation or chemical catalyst. In industrial use, the former is gamma radiation from Co-60 or beta radiation from the electron accelerator. The latter contains free radicals from the polymerization initiator such as peroxide, azo compounds, and redox system.

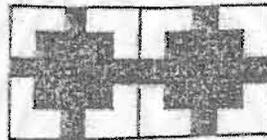
The radiation system also has a combined use of some sensitizer to the radiation or some catalyst for decreasing the total radiation dosage. The radiation process has some advantages in making WPC. First, the rate of free radical generation is constant for a given content of radiation and does not increase with temperature. Second, refrigeration is not required for monomer storage because the monomer is not being catalyzed. There is little, if any, difference in the physical properties of WPC produced by the radiation or catalyst-heat process. And, the WPC produced by beta radiation shows better dimensional stability than ones by gamma radiation in the same polymer content.

In large production, the wood-monomer is placed directly into the curing oven, usually in the basket that holds the wood during impregnation. Alternatively, it is placed in the curing vessel, which consists of a similar pipe with an insulated copper stream coil wound along its length. In the radiation-cured procedure, the thin metal container in which the wood is impregnated is flushed with nitrogen. At present, a lack of measures of monomer vaporization prevention and the removal of unreacted monomer poses a threat to the industrial WPC production. Consequently, in the future, the trends of the preventive measure of air pollution and hydrocarbon control may arise as a more serious subject matter. [7]

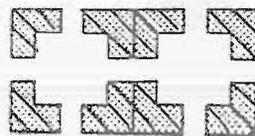
2.7 Monomer reaction and its existence in wood

The polymer location in WPC depends on the swelling of the cell wall by monomer sources, and makes three types of WPC (Figure 2.5). There are two types of porosity in the wood; cell cavities and micropores in the cell walls. The cell wall micropores are transient. Polymers in WPC can largely fill cell lumens (type 1 in Figure 2.5) or can enter the micropore.

Most of the common vinyl monomers such as MMA and ST are in the nonswelling or little-swelling category, and thus, essentially produce a cell lumen WPC (type 1). The monomers with mainly nonswelling and dilute-swelling monomer, such as hydroxy ethyl methacrylate or glycidyl methacrylate, or swelling solvent, such as mono-alcohol or dimethyl sulfoxide, produced the mixture of cell-lumen and cell wall WPC. The monomers with mainly non-swelling and dilute-swelling monomer, such as hydroxyethyl methacrylate or glycidyl methacrylate, or swelling solvent, such as mono-alcohol or dimethyl sulfoxide, produced the mixture of cell-lumen and cell-wall WPC (type 3). The material produced by swelling chemicals such as phenol-formaldehyde or poly(ethylene glycol) belongs to cell wall WPC (type 2).[7]



Type 1 Cell lumen WPC



Type 2 Cell wall WPC



Type 3 Cell lumen and cell wall WPC

Figure 2.7 Models of polymer location in WPC.

2.8 Properties of wood-polymer composites [7]

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

2.8.1 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 the untreated wood.

2.8.2 Dimensional stability

The introduction of polymers generally reduces swelling and shrinkage from water, and promotes dimensional stability. WPC especially shows more resistance to water absorption. The moisture excluding efficiency (MEE) increases in accordance with polymer loading (PL). An increase of MEE of WPC depends on the resistance of water vapor-diffusion from polymer in the cell lumen. Moreover, antishrink 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 30 to 70% of polymer loading. In general, WPC produced by MMA has larger ASE and a bigger bulking effect than that of the WPC unsaturated polyester. However, it is necessary for the polymer to remain in the cell wall of wood in order to improve the dimensional stability.

2.8.3 Manufactured properties

WPC has a fine finishing surface from sanding or buffing without surface coating. Woodworking machines cannot be used well, however, 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.

2.8.4 Decay resistance

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

2.9 Applications

There are many potential applications for WPC material (Table 2.2). Commercial production of WPC began in the mid-1960s using the radiation process in the U.S. and using the catalyst-heat process in Japan in the early 1970s. Now, there are many companies. More than five and six companies in U.S. Japan, respectively, that produce WPC products as flooring. The former is the flooring for heavy duty walking resistant to footwear, and the latter is mainly for light duty walking. Taking into account of the cost of goods installation, easy maintenance, and long-life of WPC flooring, 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, hence its requirement for WPC flooring may be superior to other flooring materials.

There are few reports searching for the practical use of wooden flooring, in spite of frequent use in office buildings, airport terminal, and private houses. There is

an excellent report on WPC flooring selection-life, maintenance, material function, and sensibility performance, among many kinds of flooring materials, such as Japanese oak wood flooring, carpets, long floor sheets, rubber floors, draining floors, and WPC flooring, for installation in the dealing room at the Tokyo Stock Market building. In Japan, a laminated type of WPC flooring has been produced, using unsaturated polyester-styrene monomers cured in a hot press, for light duty walking in private houses. There are many potential applications for WPC. Therefore, many companies have produced many WPC products, but its market is still small. Some commercial application of WPC products are listed in Table 2.2.

Table 2.2 Some commercially products of WPC goods

Item	Goods
Housing	Flooring
	Stairs
	Sundeck floors
Furniture	Desks
	Chairs
Sports and leisure	Archery bows
	Golf clubs
Stationery	Letter holders
	Stationery stones
Others	Bowls
	Railroad ties
	Truck beds

2.10 Literature review

During the past three decades, researchers have impregnated wood with a variety of chemicals to produce WPC and investigated their properties. There have

been many interesting literature reviews about WPC materials, processes, properties, and products.

Rozman, Kumar, and Abusamah,[15] 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.

Hazer, Ors, and Alma,[6] 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 antiswell efficiency (ASE) value increase with an increase in weight percent gain. Improvements of 19.12% in longitudinal compression and 25% in bending strength were also achieved for spruce samples with low weight percent gain. IR spectroscopy was used for chemical characterization of wood-polymer components.

Elvy, Dennis, and Loo-teck,[16] studied the catalyst-accelerator method for preparation of wood-polymer composite at ambient temperature, thus reduce the loss of the volatile monomer during curing, which is a major disadvantage of the heat-catalyst method. The combination of peroxide initiators which an aromatic amine accelerator was optimized for the methyl methacrylate system. Polymer loading and mechanical properties of WPC prepared from *Pinus radiata* using the catalyst-accelerator method were compared with those obtained using the gamma radiation

method. The catalyst-accelerator method has been shown to have advantages over the gamma radiation curing method.

Mubarak, Khan, and Idriss Ali,[17] prepared wood plastic composites with low density wood simul under Co-60 gamma radiation using acrylamide (AM), butyl methacrylate (BMA), and styrene (ST) as the bulk monomers at different compositions. Methanol was used as swelling agent. The effect of additives, e.g., polyfunctional monomers and oligomers used by 1% v/v or w/v, on the polymer loading and tensile strength of the composites is investigated. The increase of polymer loading (PL) with enhanced tensile strength (TS) are obtained with the composite. Incorporation of a small amount of coadditives into the impregnating solutions containing the additives has significantly influenced the PL and TS values of the WPC.

Rungvichaniwat [18] prepared para rubberwood-epoxy resins composites by impregnation para rubberwood with epoxy resin mixture under reduced pressure. The effect of diluent type, diluent content, hardener content related to the viscosity and cure time of prepolymer mixtures were studied. Impregnation conditions such as evacuating time, soaking time and evacuating process were varied to various conditions in the preparation process. Dimensional stability and mechanical properties of impregnated samples were compared with natural para rubberwood. The resulting WPC gave significant lower water absorption, higher antishrink efficiency than natural para rubberwood. Modulus of elasticity, flexture stress, compression parallel to grain were improved and specific gravity was higher than those of natural para rubberwood.

Kasamchainanta [19] prepared durianwood-polyester resins composites by impregnation under reduced pressure. The effect of diluent content, initiator types, initiator content that related to viscosity and cure time of prepolymer mixtures were studied. Impregnation parameters such as evacuating time, soaking time were varied to various conditions in preparation process. Physical and mechanical properties of impregnated samples were compared with natural durianwood. The result showed that modulus of elasticity, flexure stress, compression parallel to grain were improved and density were higher than those of natural durianwood.



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CHAPTER III

EXPERIMENTAL PROCEDURES

3.1 Materials

3.1.1 Para rubberwood

The small pieces of para rubberwood were obtained from Bangkok Shuttle Industry Co., Ltd. The samples used in this study were sawn into specimens of 10 x 25 x 100 mm. (radial x tangential x longitudinal directions) for flexure stress tests and modulus of elasticity tests (ten specimens for each type of tests); 10 x 10 x 30 mm. for compression parallel to the grain tests (ten specimens); 25 x 25 x 5 mm. for water absorption (five specimens); and 20 x 20 x 10 mm. for termites tests (five specimens).

3.1.2 Chemicals

3.1.2.1 Styrene

Styrene was supplied by Siam Chemical Industry Co., Ltd.

3.1.2.2 Butylacrylate

Butylacrylate was supplied by Siam Chemical Industry Co., Ltd.

3.1.2.3 Acrylamide

Acrylamide was supplied by Siam Chemical Industry Co., Ltd.

3.1.3 initiator

3.1.3.1 Benzoyl peroxide

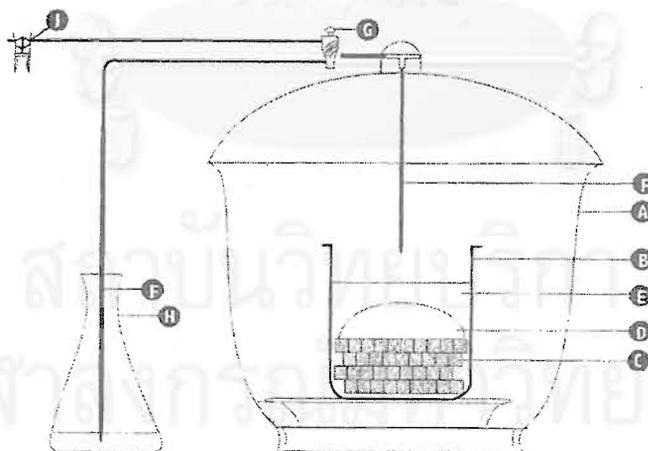
Benzoyl peroxide was obtained from Siam Chemical Industry Co., Ltd. Its tradename is NYPER BO, 50% white paste.

3.1.3.2 Methyl ethyl ketone peroxide

Methyl ethyl ketone peroxide was obtained from Siam Chemical Industry Co., Ltd. Its tradename is Peroximon K10.

3.2 Apparatus and equipments

1. Vacuum Chamber : modified from 8 inches diameters dessicator
2. Vacuum Pump : SUPERPOWER, Thailand
3. Vernier : MITUTOYO, Japan
4. Vacuum Oven : MUTTER, Germany
5. Sandpaper : WATER PROOF NO.80
6. Electric saw : PEHAKA, England
7. Brookfield Viscometer : BROOKFIELD, United state of America
8. Scanning Electron Microscope : JSM-6400, JEOL Co., Ltd., Japan
9. Dessicator
10. Polyvinyl chloride cups



- 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

Figure 3.1 Apparatus for vacuum impregnation

3.3 Experimental procedures

3.3.1 Preparation of para rubberwood-polymer composites

3.3.1.1 Preparation of wood specimen

Pieces of wood were sawn to the test specimens size by using electric saw. The rough surface was polished by sandpaper in order to move out the woolly fiber and made smooth surface. Thus, the precise measurement of the dimension can be made.

3.3.1.2 Determination of moisture content and density of specimens

Each of the prepared test specimens was weighed accurately to 0.1 g. Then, it is dried in oven at 105 °C overnight. Next day, the dried specimens were cooled down in dessicator and weighed again. Moisture content in each sample was calculated using 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 were determined. Therefore, density can be calculated using the relationship below.

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

Where V = volume of specimen after drying

3.3.1.3 Preparation of impregnation styrene-co-butylacrylate mixtures

Styrene (ST) was weighed in beaker. Then, the desired amount of butylacrylate (BA) was added and mixed homogeneously. At the feeding time of the prepolymer mixtures, the weighed initiator was added into the mixture and mixed slowly to allowed the initiator to spread in all parts of the mixture.

3.3.1.4 Preparation of inpregnation styrene-co-acrylamide mixtures

Styrene (ST) was weighed in beaker. Then, the desired amount of acrylamide (AM) was added and mixed homogeneously. At the feeding time of the prepolymer mixtures, the weighed initiator was added into the mixtures and mixed slowly to allowed the initiator to spread in all parts of the mixture.

3.3.1.5 Preparation of para rubberwood–poly(styrene-co-butylacrylate) composites

Each dry wood specimens was marked with waterproof ink and put into the dessicator as the vacuum chamber. The vacuum chamber was connected with the vacuum pump. At first, the connection valve was opened and turned on the vacuum pump. Gas in dessicator was allowed to evacuate untill the specified time, then, the vacuum pump was turned off. After that the appropriate prepolymer mixtures were introduced and the specimens were left immersed until atmospheric pressure was attained. The chamber was left at room temperature for specified time. The specimens were removed from the chamber, and excess impregnant was wiped off from wood surfaces. The wood samples were wrapped in aluminium foil and then placed in an explosion-proof oven curing. After unwrapping, the samples were again oven dried at 100 °C for 24 hours to remove unreacted monomer. The specimens were cooled down in the dessicator, then weighed to determine the polymer loading.

3.3.1.6 Preparation of para rubberwood-poly(styrene-co-acrylamide) composites

The preparation process is as same as in 3.3.1.5.

3.3.2 Study of appropriate condition for para rubberwood-polystyrene composite preparation

3.3.2.1 Effect of evacuating time on properties

Para rubberwood-polymer composites were prepared from prepolymer mixtures that contained 100 phr. styrene monomer and 1 phr. initiator. Four diffent evacuating times, 0.5, 1, 2 and 3 hours were set in order to investigate the effect of evacuating time on rubberwood properties. While soaking time was set at 4 hours.

3.3.2.2 Effect of soaking time on properties

The para rubberwood-polymer composites were prepared from prepolymer mixtures that contained 100 phr. styrene monomer and 1 phr. initiator. Four different soaking times at 2, 4, 6 and 8 hours were set in order to investigate the effect of soaking time on rubberwood properties. While evacuating time was set at 2 hours.

3.3.3 Study of factors effecting in the preparation para rubberwood-polymer composites

3.3.3.1 Initiator type effecting on preperities of WPC

Two types of initiators, benzoyl peroxide (BPO) and methyl ethyl ketone peroxide (MEKPO), in equal amount (2 phr) were investigated.

3.3.3.1.1 Benzoyl peroxide (BPO)

Benzoyl peroxide at 2 phr was added into each prepolymer mixture containing 100 phr. styrene monomer. The impregnation parameters were as follows : 2 hours evacuating time and 4 hours soaking time. After impregnation, the wood samples were wrapped in aluminium foil and then placed in an oven at 100 °C for 24 hours.

3.3.3.1.2 Methyl ethyl ketone peroxide (MEKPO)

Methyl ethyl ketone peroxide at 2 phr. was added into each prepolymer mixture containing 100 phr. styrene monomer. The impregnation parameters were set at 2 hours evacuating time and 4 hours soaking time. After impregnation, the wood samples were wrapped in aluminium foil and then placed in an oven at 100 °C for 24 hours.

3.3.3.2 Initiator contents effecting on properties

Initiator contents at 1 phr., 2 phr., and 3 phr. were added into prepolymer mixtures containing 100% by weight styrene monomer. The evacuating time and soaking time were set at 2 hours and 4 hours, respectively, during impregnation process.

3.3.3.3 Effect of monomer ratio on properties of WPC

Monomer ratios of styrene:butylacrylate (ST:BA) or styrene:acrylamide (ST:AM) are listed in Table 3.1

Table 3.1 Monomer ratio used in impregnation

Sample	Monomer Systems		
1	100:0	+	2 % BPO (by weight)
2	80:20	+	2 % BPO (by weight)
3	60:40	+	2 % BPO (by weight)
4	50:50	+	2 % BPO (by weight)
5	40:60	+	2 % BPO (by weight)
6	20:80	+	2 % BPO (by weight)
7	0:100	+	2 % BPO (by weight)
8	Untreated wood (controls)		

The impregnation parameters were set as following ; 2 hours evacuating time and 4 hours soaking time.

3.3.4 Characterization of para rubberwood-polymer composites

3.3.4.1 Physical properties

3.3.4.1.1 Polymer loading (PL) [6]

Before impregnation, the specimens were dried in an oven at 80 °C overnight and sample weight were determined. After impregnation, the wood composites specimens were obtained. They were weighed again, then the polymer loading were calculated using the relationship below.

$$\text{Polymer loading (\%)} = \frac{W_1 - W_0}{W_0} \times 100$$

Where W_1 = Weight of treated wood or wood polymer composites

W_0 = Weight of untreated wood (oven dry)

3.3.4.1.2 Density of specimens

By knowing the weight and dimension or volume of wood composites specimens, density can be calculated using the following relationship :

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

W = Weight of specimens

V = Volume of specimens

3.3.4.1.3 Water Absorption (WA) [6]

Wood composites specimens were weighed accurately to 0.1 g. Then, they were placed vertically in the vessel. The distilled water was added until the upper surface of specimens was about 25 mm. under the surface

of water. The specimens were soaked for 24 hours at room temperature. After that, the specimens were taken out of water, dabbed dry and weighed. The water absorption of the specimens were calculated as followed :

$$\text{Water absorption (\%)} = \frac{W_1 - W_0}{W_0} \times 100$$

Where W_1 = Weight of specimens after water soaking

W_0 = Weight of specimens before water soaking

3.3.4.1.4 Antiswell efficiency (ASE) [6]

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

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

Where V_1 = Wood volume after water soaking

V_0 = Wood volume before water soaking

$$\text{Antiswell efficiency (ASE)} = \frac{S_1 - S_0}{S_0} \times 100$$

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 Flexure stress and Modulus of Elasticity (MEO)

[ASTM D3043-87]

The width and thickness of wood composite specimens were measured and used as input data to the softwares of testing machine before running the test. Then, flexure stress and modulus of elasticity values were determined. The MOE, corresponding to the slope of the linear portional limit, can be calculated from the stress-strain curve as the change in stress causing a corresponding change in strain.

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

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

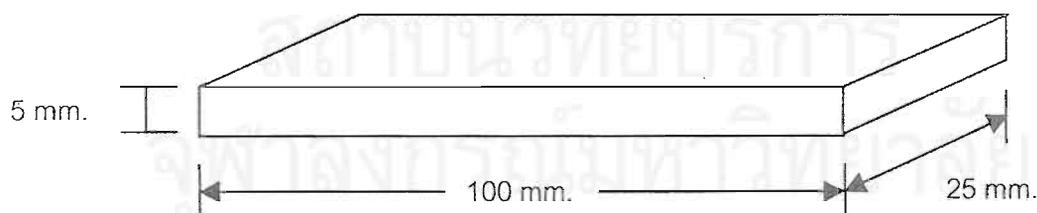


Figure 3.2 Dimension of flexure stress and MOE testing specimen

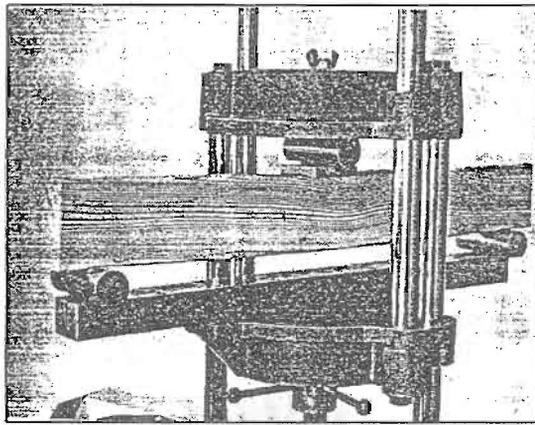


Figure 3.3 A process of making flexure stress test
in an universal testing machine

3.3.4.2.2 Compression parallel to grain [ASTM D3501]

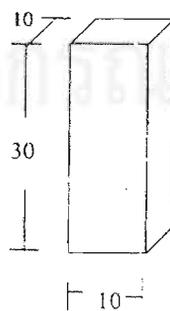
The width and thickness of wood composites specimens were measured. Maximum load were obtained after tested. The compression parallel to grain value was calculated as followed :

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

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

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

The dimension of testing specimen is shown in Figure 3.4



Unit : mm.

Figure 3.4 Dimension of compression parallel to grain testing specimen.

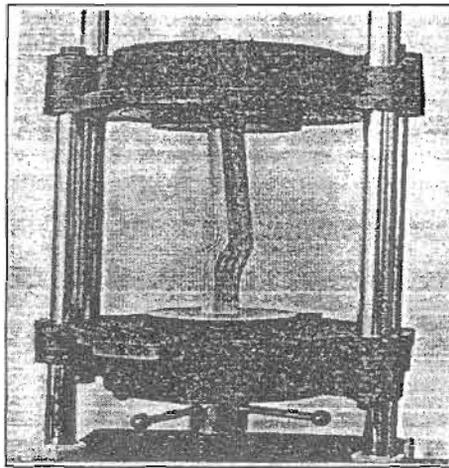


Figure 3.5 A process of making compression test
in an universal testing machine

3.3.4.3 Evaluation of WPC specimens for termites resistance

[ASTM D3345]

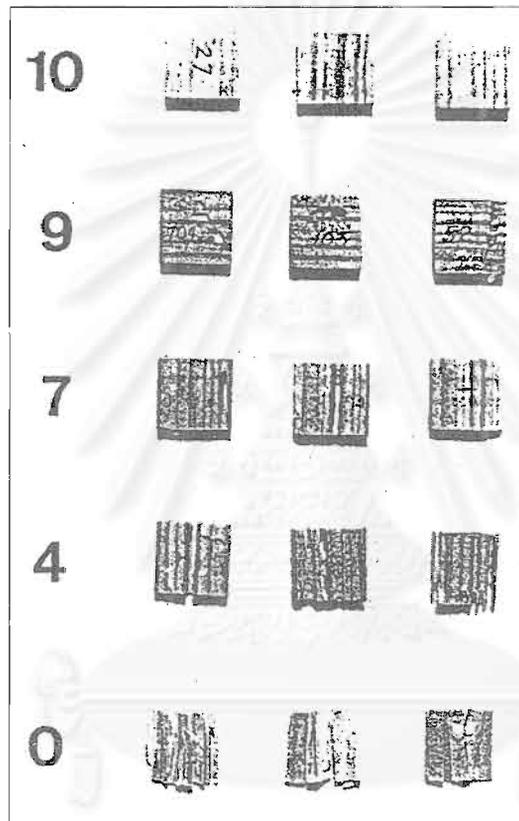
In this study, three types of wood, para rubberwood, Teakwood and Redwood, were compared with WPC specimens. Prior to test, the container was prepared by washing and rinsing with antiseptic solution and dry. The size of specimens were 20x20x10 mm. and then weighed before testing. The prepared specimens were placed in the bottom of the containers. Two hundred gram of clean sand was added in the container. The amount of distilled water were determined in equation, as follows :

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

Calculate the percent saturation as follows :

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

After addition of water, the container was left overnight. The termites was weighted at 1 ± 0.05 g. and added into prepared container with loosely closed tops. The container was maintained at room temperature for 4 weeks. After 4 weeks, the containers were disassembled and the blocks were removed and cleaned. The test blocks were weighed again for % weight loss and then examined visually at each block using the following rating system :



10 = Sound, surface nibbles permitted

9 = Light attack

7 = Moderate attack, penetration

4 = Heavy

0 = Failure

Figure 3.6 Typical ratings of termite attack on test blocks.

3.3.4.4 Microstructure of WPC specimens

Microstructure of wood-polymer composite specimens were observed by scanning electron microscope and compared with microstructure figure of natural para rubberwood. The specimens were dried then coated with gold before scanning for observation.



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CHAPTER IV

RESULT AND DISCUSSION

Modified para rubberwood can be defined as a wood-polymer composites material that properties have been changed in comparison to natural para rubberwood. The para rubberwood was impregnated with styrene-butylacrylate and styrene-acrylamide mixtures in the presence of an initiator. The impregnated wood was then cured by heat treatment process.

The para rubberwood modification improved wood properties and increased the material durability. The suitable copolymer mixtures and impregnation parameters were investigated. Physical and mechanical properties of specimen were tested and evaluated in order to obtain the optimum conditions.

4.1 Characteristic of natural para rubberwood, Teakwood and Redwood

In this study, only local para rubberwood, Teakwood and Redwood were studied. The physical and mechanical properties of para rubberwood, Teakwood and Redwood were determined twice (ten specimens each) prior to the impregnation process. The results of characterization (average value from two separated determinations) are presented in Table 4.1

Table 4.1 Characteristic of natural para rubberwood, Teakwood and Redwood

Properties	Para rubberwood	Teakwood	Redwood
Density (g/cm ³)	0.6011	0.7988	0.8115
Water absorption (%)	7.28	45.72	41.39
MOE (MPa)	6398	6398	5790
Flexure stress (MPa)	93.0	98.0	82.0
Compression (N/mm ²)	40.08	86.30	82.30

4.2 Effect of evacuating times 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 evacuating time, the more void space free of air was obtained. Therefore, it improves the penetration of prepolymer mixtures to the wood cells. In this study, the evacuating time was varied from 0.5, 1, 2, and 3 hours. Results of this experiments are shown in Table 4.2 and the plot of evacuating time versus % polymer loading and density are shown in Figure 4.1

Table 4.2 Properties of para rubberwood-polystyrene composite prepared from various evacuating times

Physical properties	Evacuating time (hrs)			
	0.5	1.0	2.0	3.0
Polymer loading (%)	28.46	30.19	35.82	36.39
Density (g/cm ³)	0.6944	0.7099	0.7439	0.7587

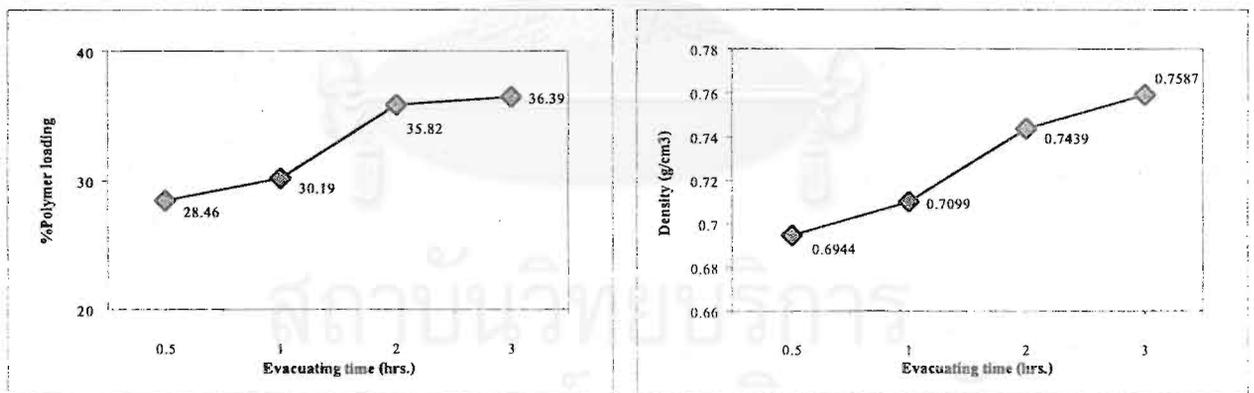


Figure 4.1 Effect of evacuating time on the physical properties of impregnated sample

The physical properties indicated that 2 and 3 hours evacuating time yielded higher polymer loading than 0.5 and 1 hour evacuating time. The longer evacuating

time, the more air evacuated from the wood cells. Consequently, it provided more opportunity for prepolymer mixture to penetrate into empty wood cells and retained in there. The amount of polymer filled in the wood cells resulted in increasing of the wood density.

When polymer loading increased, more polymer could be penetrated into void space of wood and increased rapidly between evacuated time of 1 to 2 hours. After that, the values of polymer loading were not significantly improved. Therefore, 1 hour evacuating time is enough for preparing para rubberwood-impregnated samples.

4.3 Effect of soaking time on the properties of impregnated samples

Soaking time is important in impregnation process. It is the duration that the specimens were soaked in the polymerizable mixtures. The soaking times were varied from 2, 4, 6 and 8 hours, while the evacuating time was fixed at 2 hours. The properties of the impregnated samples of different soaking time (average value from two separated determinations with ten specimen each) are shown in Table 4.3. The plots of soaking time versus % polymer loading and density are shown in Figure 4.2.

Table 4.3 Properties of para rubberwood-polystyrene composite prepared from various soaking times

Physical properties	Soaking time (hrs)			
	2.0	4.0	6.0	8.0
Polymer loading (%)	28.62	35.82	37.59	38.56
Density (g/cm ³)	0.6995	0.7439	0.7564	0.7596

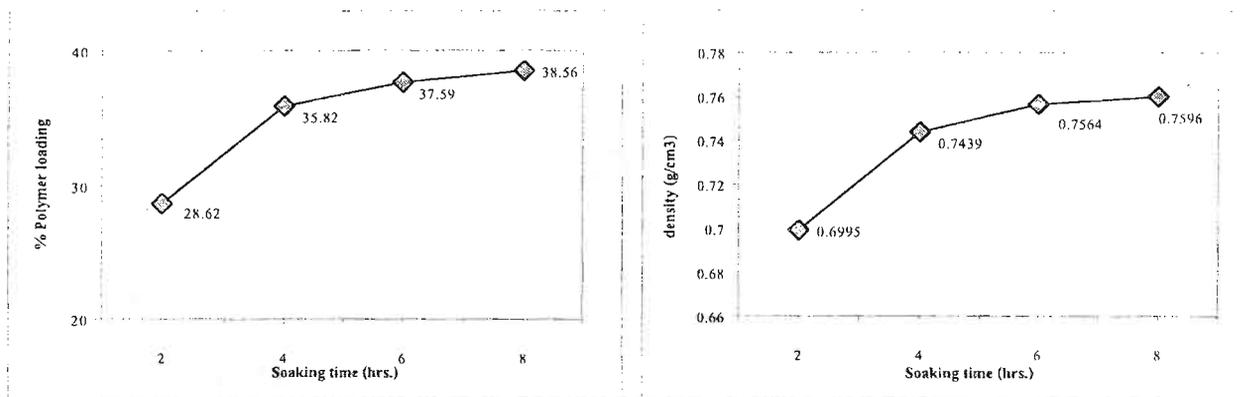


Figure 4.2 Effect of soaking time on the physical properties of impregnated sample

The results of physical properties testing have shown that the soaking time at 2, 4, 6 and 8 hours yielded 28.62, 35.82, 37.59, 38.56 % polymer loading, respectively and density of 0.6995, 0.7439, 0.7564, 0.7596, respectively. The polymer loading and density were increased in according to increasing soaking time, and increased rapidly between 2 to 4 hours. After that, the values of polymer loading and density were insignificant changed. Therefore, 4 hours soaking time is enough for preparing para rubberwood-impregnated samples, and it has been chosen for further experiment.

From the literature review [18], the results of polymer loading at 30, 60, 75 minutes soaking time were 24, 35, 31% which in the literature review [19], the results of polymer loading at 1, 2, 3 and 6 hours soaking time were 57.35, 71.42, 91.33 and 100.05%, respectively. Therefore, sampled soaked with longer time had a tendency to give higher polymer loading.

4.4 Effect of initiator type on properties

In this study, two types of initiators which were benzoyl peroxide (BPO) and methyl ethyl ketone peroxide (MEKPO) were investigated.

4.4.1 Effect of benzoyl peroxide on properties

Benzoyl peroxide is the most popular medium temperature peroxide initiator (60-120^oC). It is stable at room temperature, but decomposed readily at elevated temperature. In this experiments, 2 phr. benzoyl peroxide was used.

Parameters of impregnation process were set at 2 hours evacuating time and 2 hours soaking time. The properties of the impregnated samples (average value from two separated determinations with ten specimens each) obtained using benzoyl peroxide as initiator are shown in Table 4.4

4.4.2 Effect of methyl ethyl ketone peroxide on properties

Methyl ethyl ketone peroxide (MEKPO) is the most widely used low temperature peroxide (20-60°C) initiators. It does not lead to a full cure by itself at ambient temperature. In this study, 2 phr. MEKPO was used. Parameters of impregnation process were set at 2 hours evacuating time and 4 hours soaking time. The properties of impregnated samples (average value from two separated determinations with ten specimens each) after prepared by methyl ethyl ketone peroxide are shown in Table 4.4.

Table 4.4 Comparison of properties of WPC samples treated with BPO and MEKPO and natural para rubberwood

Physical properties	BPO	MEKPO	Untreated wood
Polymer loading (%)	48.09	44.57	-
Density (g/cm ³)	0.9214	0.8997	0.6011
Water absorption (%)	22.09	23.96	59.41
Antiswell efficiency (%)	32.39	30.10	-
Mechanical properties	BPO	MEKPO	Untreated wood
Polymer loading (%)	51.64	48.52	-
MOE (MPa)	9122	9044	6596
Flexure stress (MPa)	139.9	136.9	93.2
Polymer loading (%)	45.58	41.12	-
Compression (MPa)	90.29	87.27	40.08

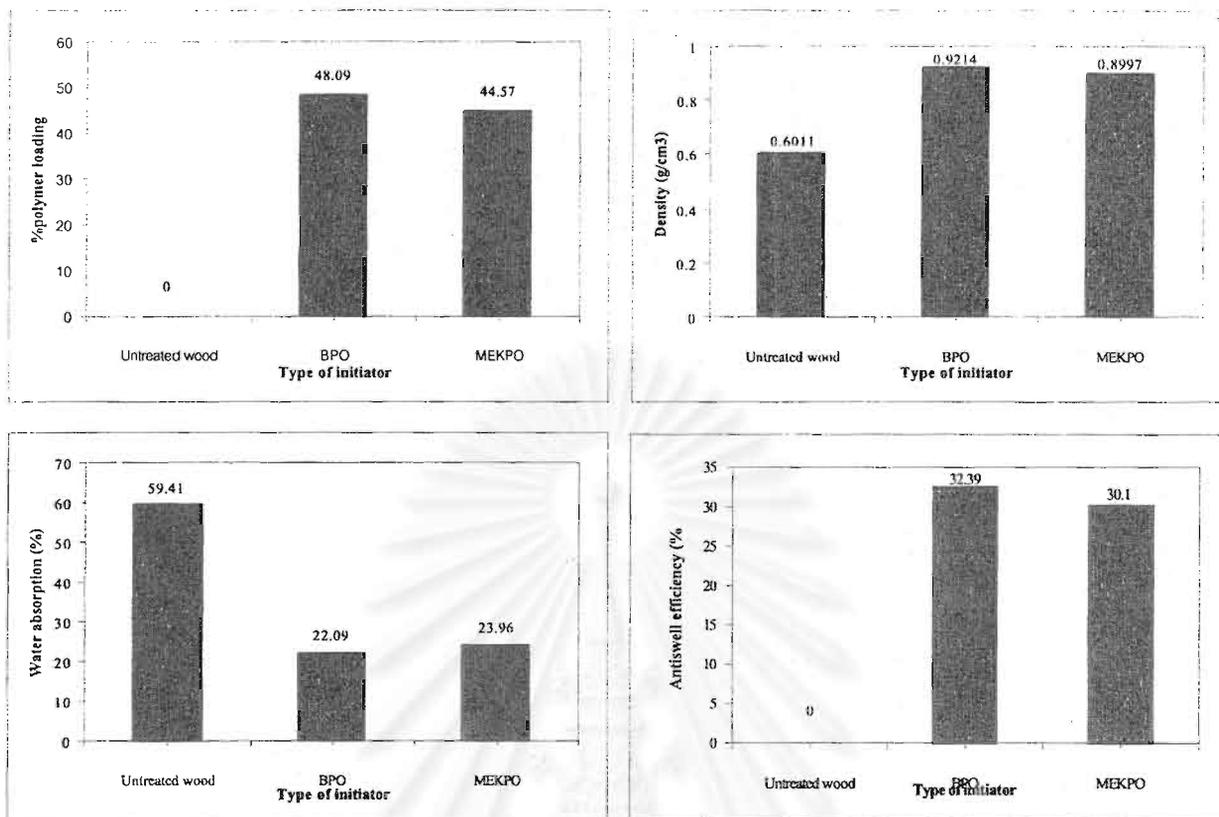


Figure 4.3 Comparison of physical properties of WPC samples treated with BPO and MEKPO and natural para rubberwood

In comparison of impregnated samples obtained using BPO and MEKPO, it indicated that samples treated with BPO gave better properties than those treated with MEKPO as shown in Table 4.4. The properties of impregnated samples treated with BPO and MEKPO were compared with natural para rubberwood as illustrated in Table 4.4, Figures 4.3 and 4.4.

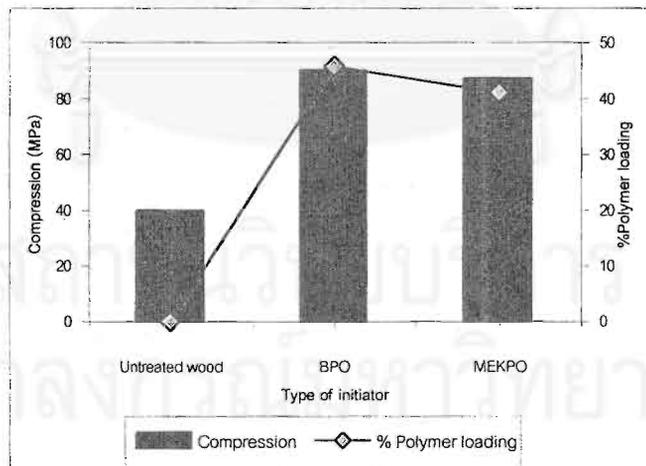
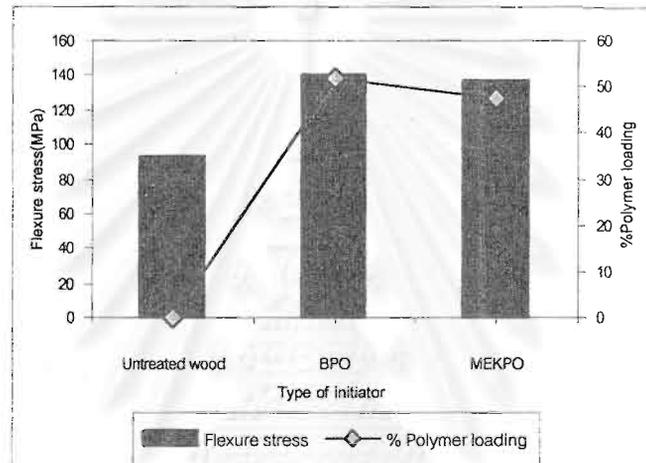
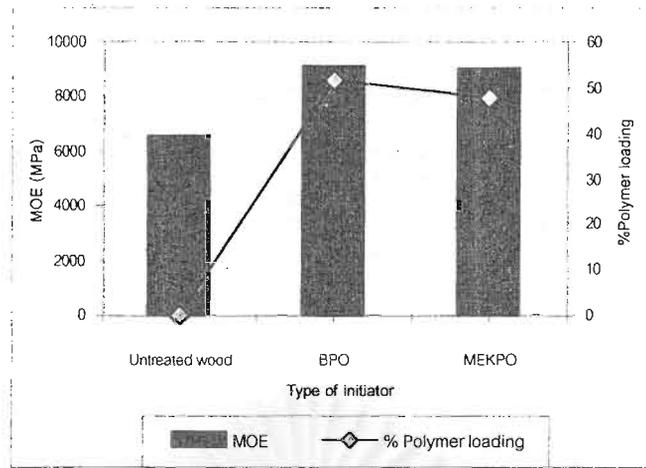


Figure 4.4 Comparison of mechanical properties of WPC samples treated with BPO and MEKPO and natural para rubberwood

From all of the test results, impregnated samples treated with BPO yielded better physical and mechanical properties than those of samples treated with MEKPO and natural para rubberwood. Thus, benzoyl peroxide was used as an initiator for further study.

4.5 Effect of initiator content on properties

As the concentration of initiator increased, the properties of impregnated wood were expected to be changed. The initiator contents were varied from 1.0, 2.0, and 3.0 phr. Parameters of impregnation process were set at 2 hours evacuating time and 2 hours soaking time. The properties of impregnated samples after being treated with different initiator contents are presented in Table 4.5, Figure 4.5 and Figure 4.6

Table 4.5 Properties of para rubberwood-polystyrene composite prepared from various initiator contents.

Physical properties	Initiator content (phr)		
	1.0	2.0	3.0
Polymer loading (%)	44.06	48.09	50.99
Density (g/cm ³)	0.9005	0.9214	0.9341
Water absorption (%)	24.69	22.09	22.74
Antiswell efficiency (%)	29.17	31.39	31.83

Mechanical properties	Initiator content (phr)		
	1.0	2.0	3.0
Polymer loading (%)	47.24	51.64	52.32
MOE (MPa)	9004	9122	9112
Flexure stress (MPa)	136.5	139.9	140.1

Polymer loading (%)	42.19	45.58	45.29
Compression (MPa)	87.67	90.29	91.65

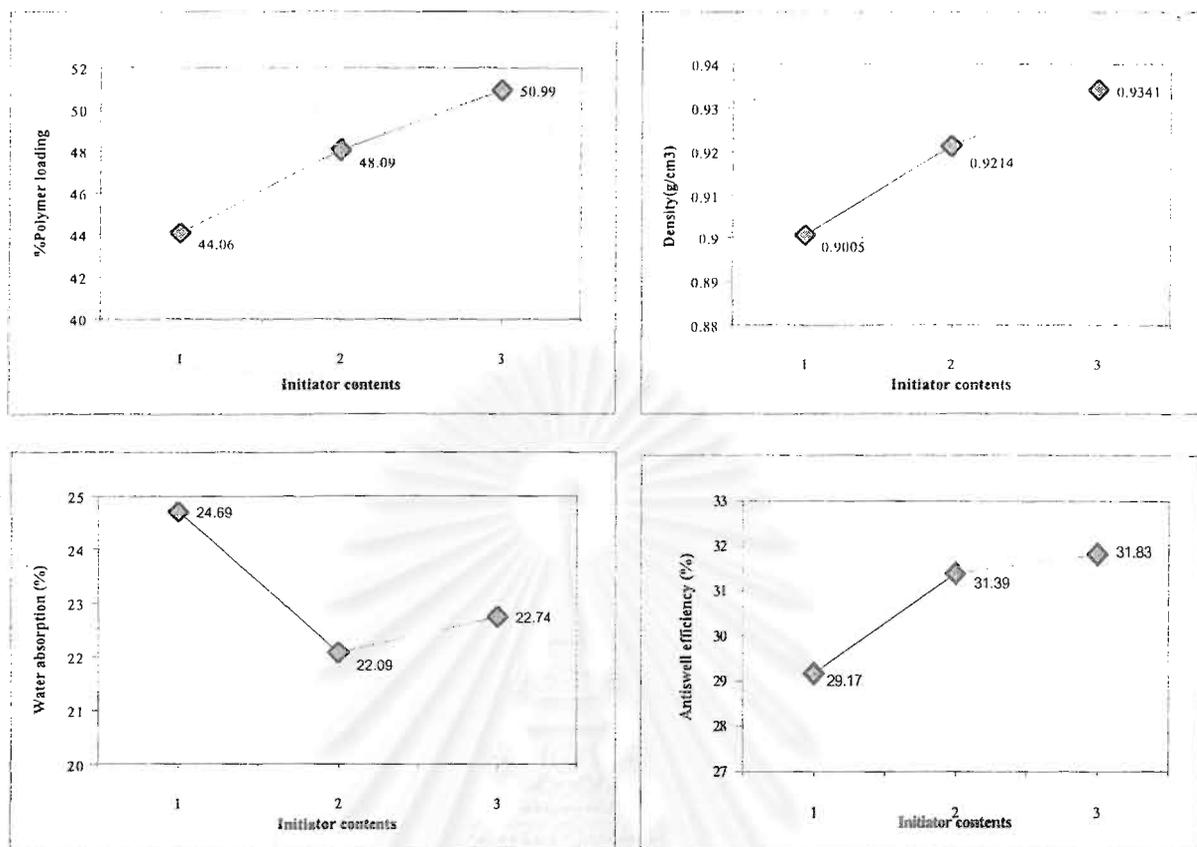


Figure 4.5 Physical properties of para rubberwood-polymer styrene composite prepared from various initiator contents

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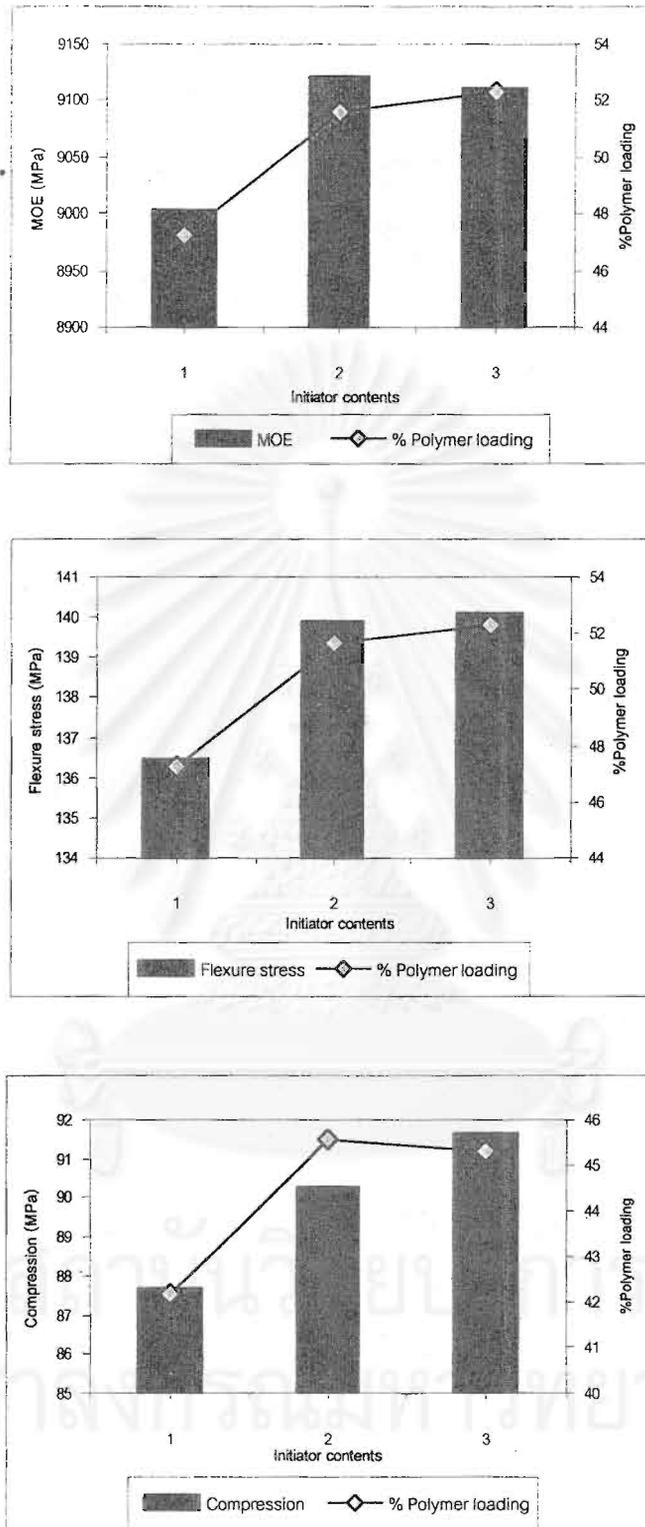


Figure 4.6 Mechanical properties of para rubberwood-polystyrene composite prepared from various initiator contents

Physical properties of impregnated sample after being treated with various initiator contents showed that polymer loading increased with increasing initiator contents. The same conclusion could be drawn for the density parameter. The water absorption of impregnated samples was reduced with increasing polymer loading. These could be explained that the increasing amount of polymer can fill up the lumen of wood, resulting in the reduction of the hydroxyl groups of wood cell wall to absorb moisture which consequent in the increasing of antiswell efficiency.

Mechanical properties of impregnated samples such as modulus of elasticity (MOE) and flexure stress after being impregnated with 2.0 phr. initiator showed higher values than those obtained from using 1.0 phr. initiator but there was not significant different values at 3.0 phr. of initiator. Compression parallel to grains of samples showed the highest values at 3.0 phr. of initiator but there was not significant difference in comparing with the compression recorded for the 2.0 phr. of initiator.

This experimental results showed that samples impregnating with 2.0 phr. of initiator in prepolymer mixture gave superior mechanical properties.

From the literature review [19], the initiator content has some effect on polymerization. When the content of initiator increased, rate of polymerization increased rapidly, resulting in the reduction of MW which has short chain molecule and the viscosity of prepolymer was increased which made it more difficult to enter the cell wall of wood. Thus, polymer loading was severely affected.

4.6 Effect of monomer ratio on properties of impregnated samples

Monomer ratio is important in impregnation process. The properties of impregnated wood were expected to be changed in according to the change of monomer ratio. Monomer ratios were varied from 100:0, 80:20, 60:40, 50:50, 40:60, 20:80, and 0:100. The parameters of impregnating process were set at 2 hours evacuating time and 4 hours soaking time. The properties of impregnated samples according to the change of monomer ratio are presented in Table 4.6, 4.7 and Figures 4.7, 4.8, 4.9 and 4.10

Table 4.6 Properties of para rubberwood-poly(styrene-co-butylacrylate) composites prepared from various monomer ratios

Physical properties	Monomer ratio (ST:BA)						
	100:0	80:20	60:40	50:50	40:60	20:80	0:100
Polymer loading (%)	48.09	48.41	49.22	49.74	48.99	49.52	51.00
Density (g/cm ³)	0.9214	0.9001	0.9213	0.9251	0.9113	0.9286	0.9308
Water absorption (%)	22.09	21.09	20.55	19.82	21.24	21.53	18.96
Antiswell efficiency (%)	32.39	36.12	37.71	36.76	34.20	37.37	38.37

Mechanical properties	Monomer ratio (ST:BA)						
	100:0	80:20	60:40	50:50	40:60	20:80	0:100
Polymer loading (%)	51.64	49.96	52.16	52.81	49.53	49.80	50.45
MOE (MPa)	9122	9745	9330	9780	10049	10165	9943
Flexure stress (MPa)	139.9	142.6	146.6	149.8	151.9	155.3	158.9

Polymer loading (%)	45.58	43.91	45.31	43.26	43.53	41.39	42.81
Compression (MPa)	90.29	86.99	82.86	77.44	74.99	70.51	63.20

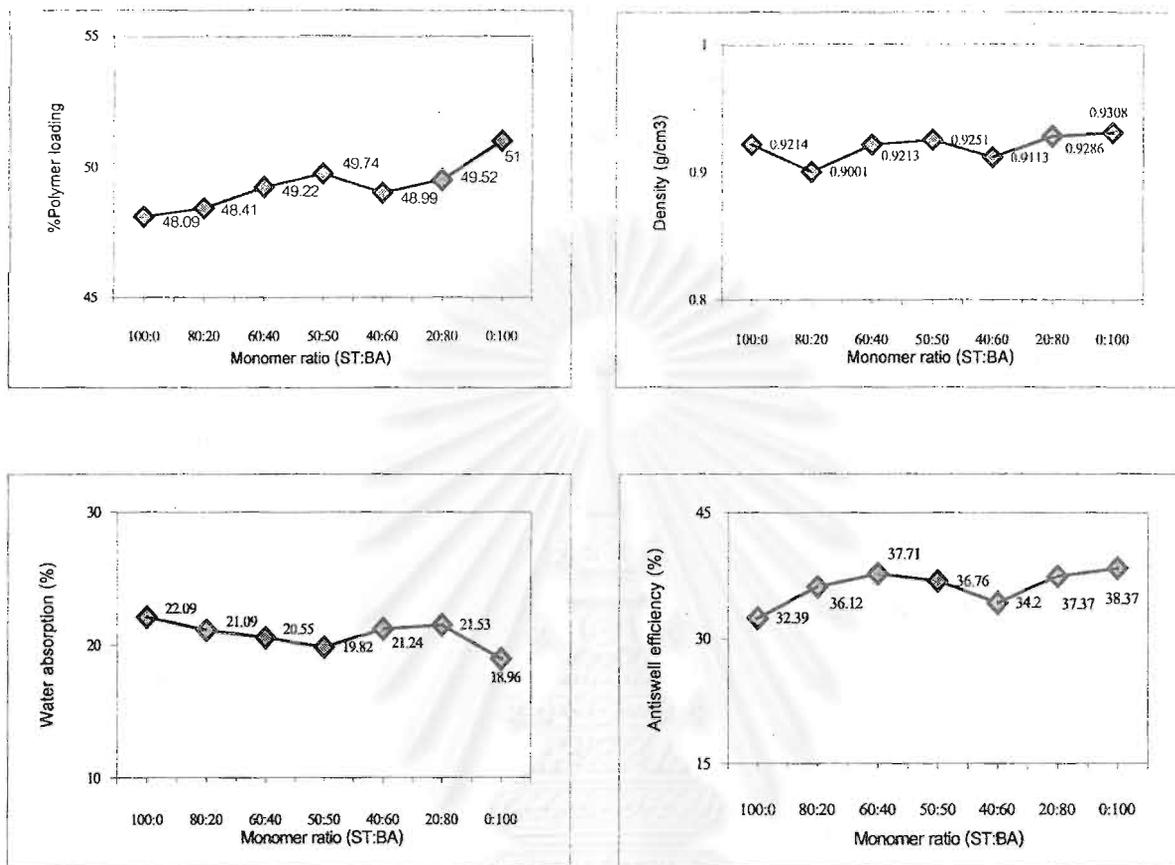


Figure 4.7 Effect of monomer ratio on physical properties prepared from various monomer ratios (ST : BA)

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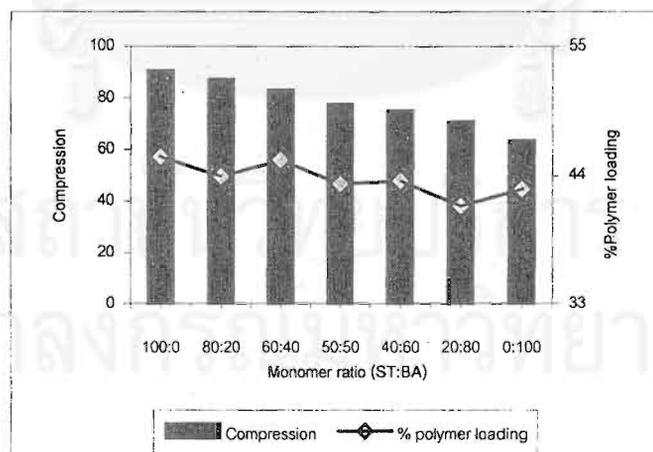
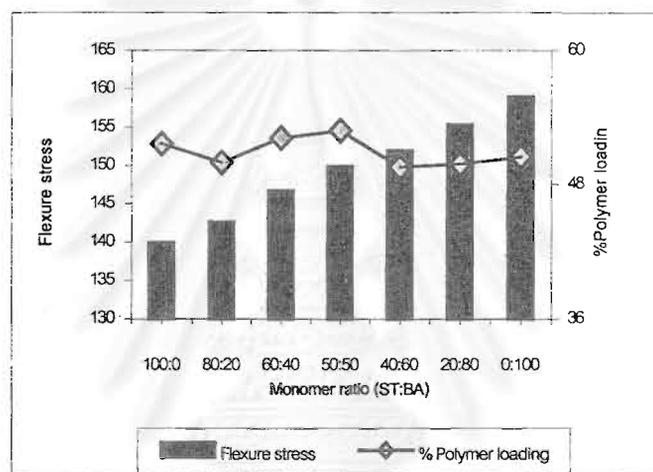
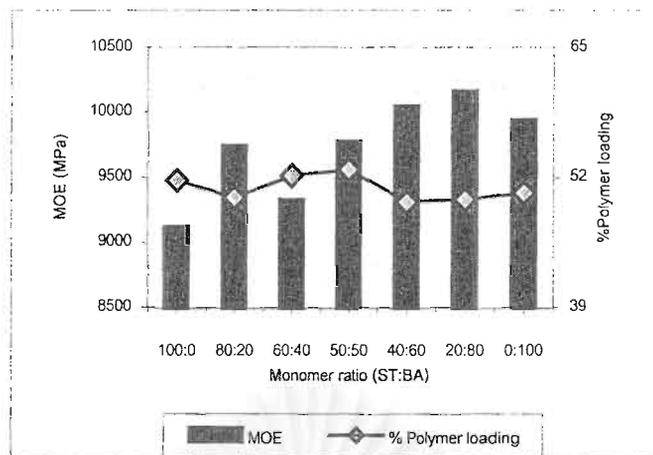


Figure 4.8 Effect of monomer ratio on mechanical properties prepared from various monomer ratios (ST : BA)

The results of physical properties testing of each monomer ratio were no significant different. The polymer loading, density, water absorption and antiswell efficiency exhibited values between 48-51%, 0.9001-0.9308 g/cm³, 19-22% and 34-38 %, respectively.

Mechanical properties of WPC obtained from each monomer ratio were different. Monomer ratio that has more styrene content gave low values of modulus of elasticity and flexure stress but compression parallel to grains were increased. When of styrene content was decreased, the modulus of elasticity and flexure stress were increased and compression parallel to grains were reduced. On the contrary, if monomer ratio that have the proportion of butylacrylate increased, modulus of elasticity and flexure stress were increased but compression were decreased. Impregnated samples with only styrene gave the highest values of compression and the lowest values of modulus of elasticity and flexure stress. On the other hand, impregnated samples with only butylacrylate gave the highest values of modulus of elasticity and flexure stress and the lowest value of compression.

The styrene monomer in the process of polymerization will change to polystyrene which is hard but fragile. Meanwhile, butylacrylate polymerizes to polybutylacrylate that has good elastic properties. Thus, para rubberwood-poly (styrene-co-butylacrylate) in each monomer ratio were exhibited the properties of the two monomers.

Therefore, the properties of WPC could be modified to be suitable for particular applications. For example, if one wants the wood to be harder, then more styrene than butylacrylate must be used. But if one wants the wood to be more flexible property, then, more butylacrylate than styrene must be used.

Table 4.7 Properties of para rubberwood-poly(styrene-co-acrylamide) composites prepared from various monomer ratios

Physical properties	Monomer ratio (ST:AM)						
	100:0	80:20	60:40	50:50	40:60	20:80	0:100
Polymer loading (%)	48.09	32.02	23.11	18.95	15.86	18.33	25.03
Density (g/cm ³)	0.9214	0.8212	0.7588	0.7173	0.6921	0.7252	0.7633
Water absorption (%)	22.09	29.73	31.71	32.11	34.25	33.34	27.50
Antiswell efficiency (%)	32.39	25.97	27.90	26.51	25.43	24.84	34.14

Mechanical properties	Monomer ratio (ST:AM)						
	100:0	80:20	60:40	50:50	40:60	20:80	0:100
Polymer loading (%)	51.64	35.68	25.01	19.87	17.22	18.60	23.81
MOE (MPa)	9122	9194	8684	8016	7782	7750	7951
Flexure stress (MPa)	139.9	131.3	125.3	121.9	120.8	117.8	115.4

Polymer loading (%)	45.58	31.96	23.21	18.94	16.56	17.20	24.79
Compression (MPa)	90.29	81.98	74.92	70.73	66.96	69.71	71.06

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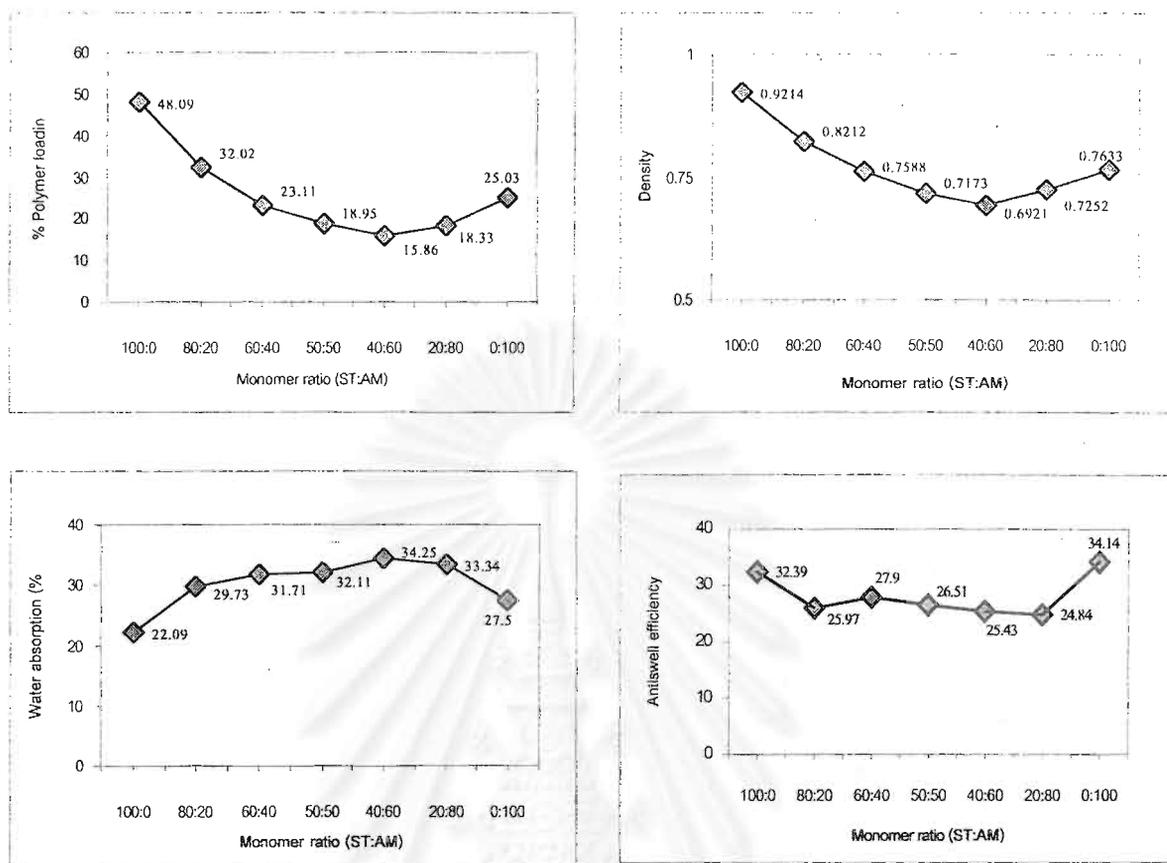


Figure 4.9 Effect of monomer ratio on physical properties prepared from various monomer ratios (ST : AM)

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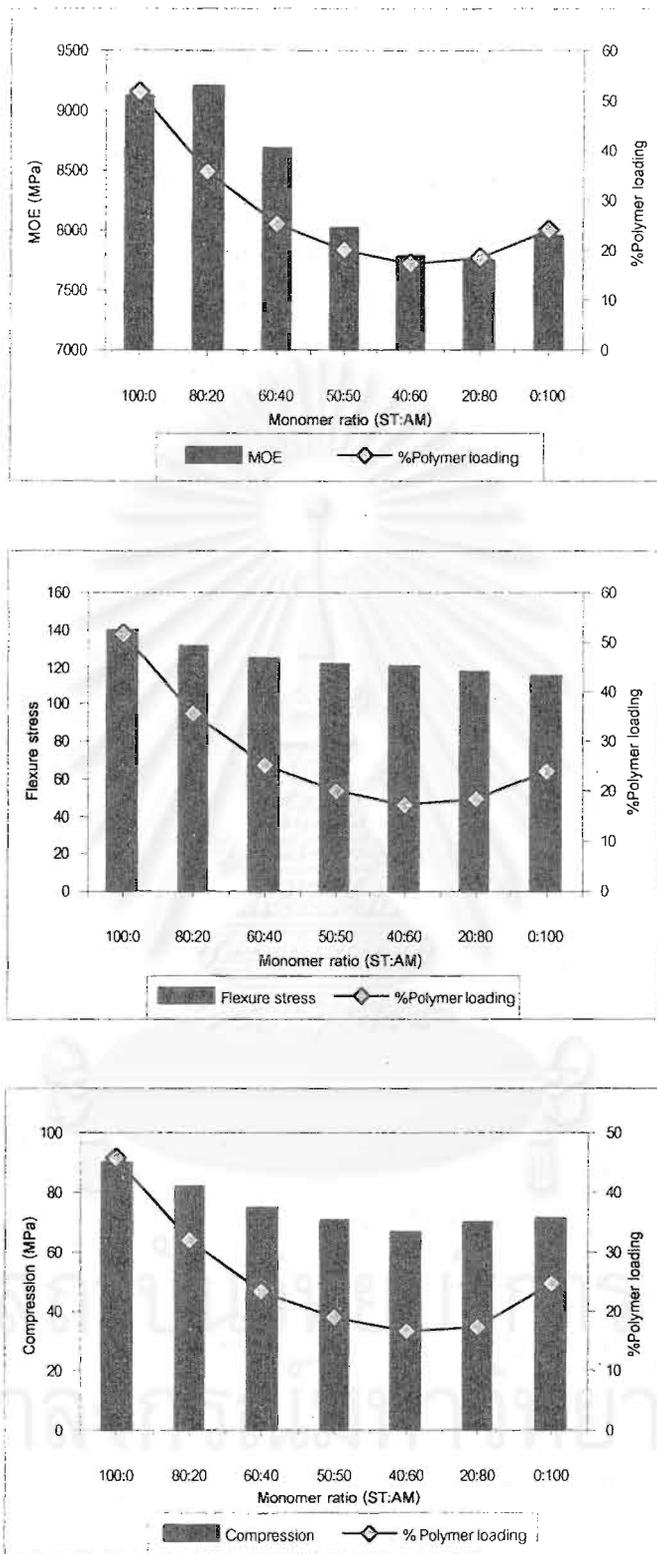


Figure 4.10 Effect of monomer ratio on mechanical properties prepared from various monomer ratios (ST : AM)

From Figure 4.9, polymer loading of wood-polymer composites prepared from varying monomer ratio showed that polymer loading decreased with increasing the proportion of acrylamide, resulting in the decrease of density of treated sample with each monomer ratio, but water absorption were increased which showed significant improvement at about 22-34 %. Therefore, the degree of polymer loading influenced the water absorption behavior of impregnated woods.

Mechanical properties of impregnated samples such as modulus of elasticity, flexure stress and compression were decreased with increasing acrylamide content, and decreased to the lowest values at 40:60 of monomer ratio.

When comparing the properties of para rubberwood-poly(styrene-co-butylacrylate) and para rubberwood-poly(styrene-co-acrylamide), it indicated that the physical and mechanical properties of para rubberwood-poly(styrene-co-butylacrylate) were higher than those of para rubberwood-poly(styrene-co-acrylamide). Therefore, poly(styrene-co-butylacrylate) was chosen to be used as wood-polymer composite.

4.7 Evaluation of WPC specimens for resistance to termites

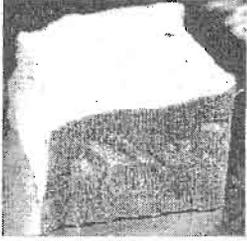
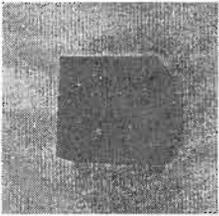
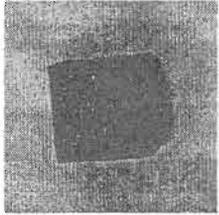
The annual loss in forest products of various kinds, resulting from deterioration by wood-boring insects, such as subteranean termite. The damage occurs in standing trees, green saw logs, unseasoned lumber and other products as well as in seasoned material in storage and in use. Preservative wood with monomers is one way to prevent damage from termites. In this experiment, four types of woods such as untreated para rubberwood, para rubberwood treated with monomers, Teakwood and Redwood were used to investigate the termite resistance. The results are shown in Tables 4.8 and 4.9.

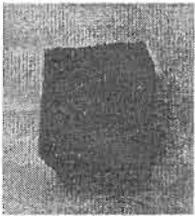
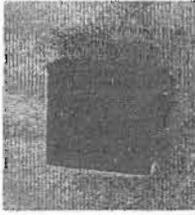
Table 4.8 The results of wood before and after testing for termite resistance

Types of wood	Weight before test (g)	Weight after test (g)	Weight loss (%)
Untreated wood	3.06	2.10	31.00
Treated wood			
100% ST	4.25	4.25	0.00
100% BA	4.62	4.62	0.00
100% AM	3.96	3.96	0.00
50%:50% (ST:BA)	4.45	4.45	0.00
50%:50% (ST:AM)	4.05	4.05	0.00
Teakwood	2.98	2.98	0.00
Redwood	3.05	3.05	0.00

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Table 4.9 The result of rating of termite attack

Types of wood	Rating of termite attack
 <p data-bbox="325 653 534 685">Untreated wood</p>	7
 <p data-bbox="268 1047 601 1080">Treated wood (100% ST)</p>	10
 <p data-bbox="282 1410 619 1442">Treated wood (100% BA)</p>	10
 <p data-bbox="272 1754 601 1787">Treated wood (100%AM)</p>	10

Types of Wood	Rating of termite attack
 <p data-bbox="268 573 651 610">Treated wood (50ST : 50BA)</p>	10
 <p data-bbox="244 901 632 937">Treated wood (50ST : 50AM)</p>	10
 <p data-bbox="382 1224 518 1261">Teakwood</p>	10
 <p data-bbox="386 1543 511 1580">Redwood</p>	10

From Table 4.8, in the container with the combination of untreated para rubberwood, treated para rubberwood, Teakwood and Redwood, it was found that termite preferred to attack untreated para rubberwood more than the others, which resulted in the highest weight loss at 31% by wt. Moreover, fungi was observed on untreated para rubberwood too. The other woods such as treated para rubberwood, Teakwood and Redwood were not damaged by termite and fungi under the tested condition.

From the literature review [19], durianwood impregnated with unsaturated polyester resin could be resistance to termite very well.

Therefore, para rubberwood impregnated with poly(styrene-co-butylacrylate) and poly(styrene-co-acrylamide) were more resistant to termite and fungi than untreated para rubberwood which corresponded well with that reported in the literature [19].

4.8 Scanning Electron Microscopy (SEM) of WPC

The microstructure of wood-polymer composite (WPC) were examined by scanning electron microscopy (SEM) of transverse sections of the specimens. The microstructure of untreated para rubberwood cells are shown in Figures 4.11 and 4.13. The microstructures of impregnated wood cells are shown in Figures 4.12 and 4.14.

From Figures 4.11, 4.12, 4.13 and 4.14 the microstructure of untreated para rubberwood cells showed the empty void space. In impregnation process, the empty wood cells were filled with polymer, which were important consequence on improvement of physical and mechanical properties of natural para rubberwood.

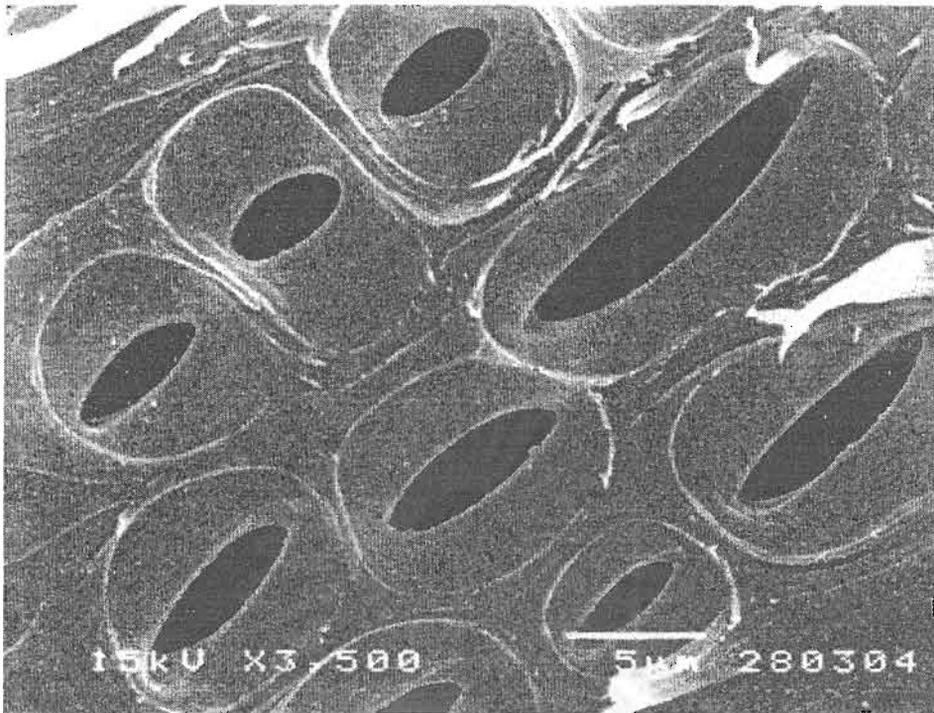


Figure 4.11 SEM micrograph of transverse section of empty wood cells (3,500 x)

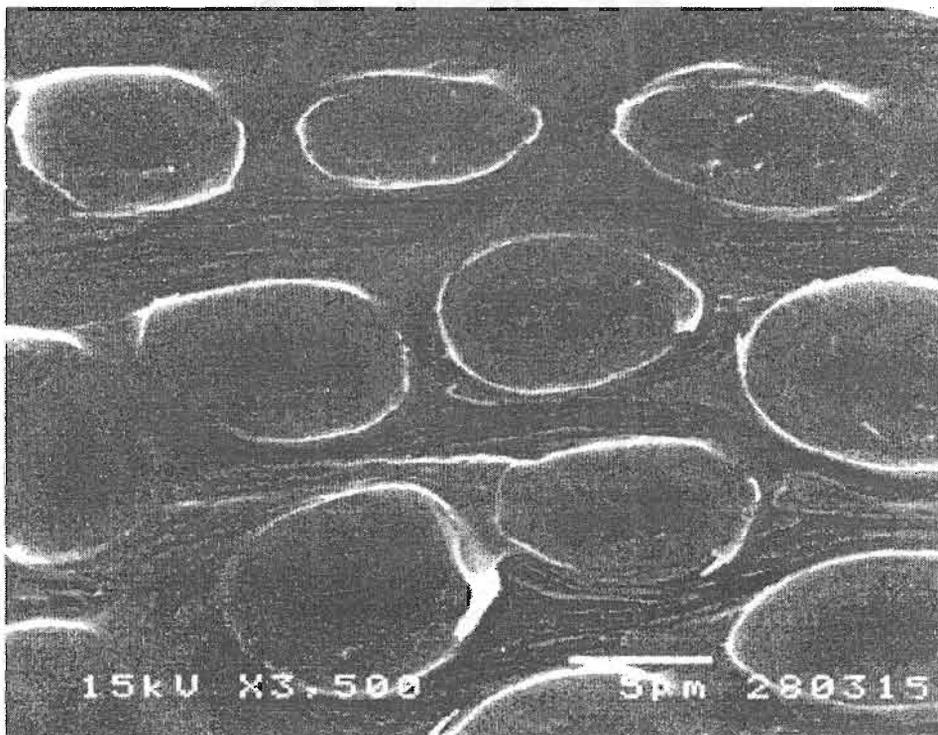


Figure 4.12 SEM micrograph of transverse section of polymer filled cells (3,500x)

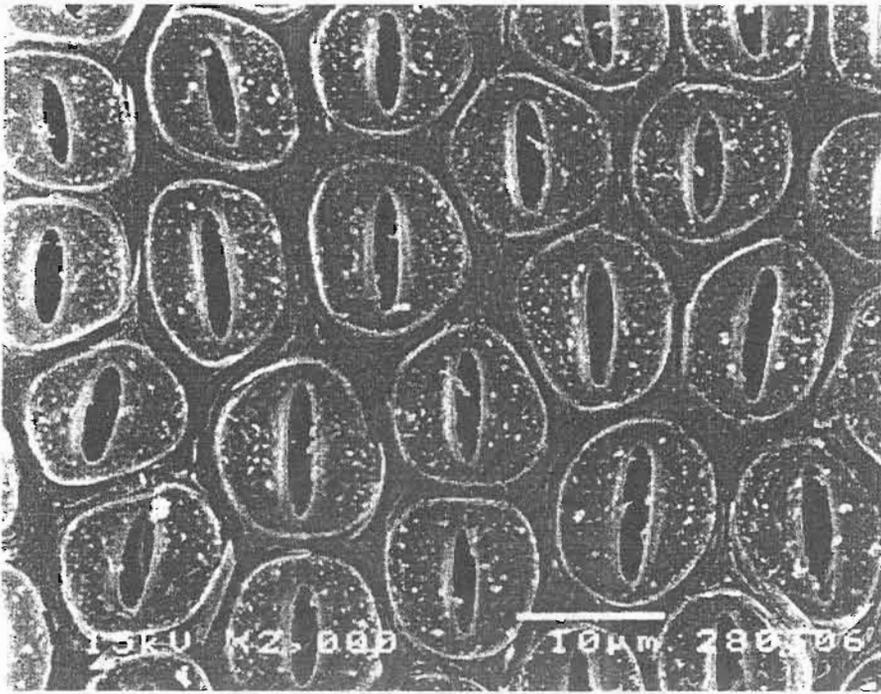


Figure 4.13 SEM micrograph of transverse section of empty wood cells (2,000x)

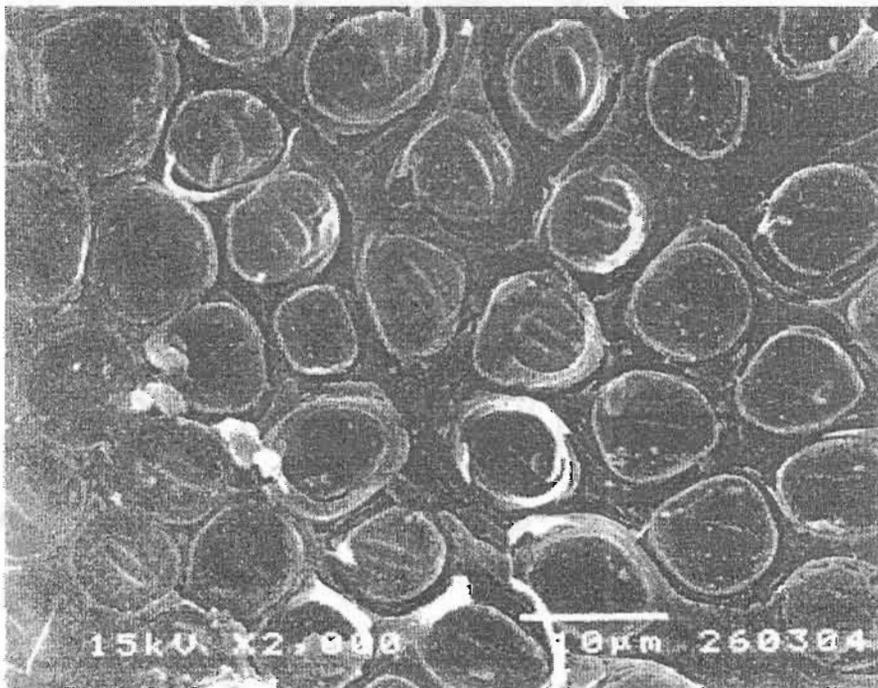


Figure 4.14 SEM micrograph of transverse section of polymer filled cells (2,000x)

4.9 Application of para rubberwood-polymer composites

In this study, the para rubberwood was improved in both physical and mechanical properties that some properties were better than the hardwood. The comparison of wood properties are shown in Table 4.10.

Table 4.10 Comparison of the mechanical properties of para rubberwood-polymer composites with other woods

Types of wood	Mechanical properties		
	MOE	Flexure stress	Compression
Untreated para rubberwood	6596	93.0	40.08
Para rubberwood-poly(styrene-co-butylacrylate) composites (50:50)	9780	150	77.44
Para rubberwood-poly(styrene-co-acrylamide) composites (50:50)	8016	122	70.73
Rubberwood-epoxy resin composite ^[18]	9271	154	72.00
Durianwood-polyester resin composites ^[19]	11790	180	75.90
Teakwood	6398	98	86.30
Redwood	5790	82	82.30

From Table 4.10, it indicated that para rubberwood impregnated with various monomers could improved mechanical properties of untreated para rubberwood. Modulus of elasticity and flexure stress of treated para rubberwod are higher than those of Teakwood and Redwood but compression is lower. Mechanical properties of durian-polyester resin composite are the best .

In this study, the process would solve the problem of wood physical and mechanical properties. The physical properties of WPC are better understood and

specific commercial products are taking advantages of the desirable appearance, high compression strength, increased hardness and abrasion resistance, and improved dimensional stability.

4.10 The cost of raw materials

The cost of para rubberwood-polymer composites which compared to the natural para rubberwood can be evaluated as follows:

The prices of materials are :

Natural para rubberwood	70	bath/ft ³
Styrene	40	bath/kg.
Butylacrylate	55	"
Acrylamide	130	"
Benzoyl peroxide	400	"

In one batch, ten specimens each of wood were impregnated all in monomer mixtures 150 g. Therefore, the costs of impregnated samples are shown in Table 4.11.

Table 4.11 The cost of para rubberwood-polymer composites

	Para rubberwood-polymer composites				
	ST	BA	AM	ST/BA	ST/AM
Cost (Bath/ft ³)	189.40	219.25	458.05	209.39	319.39

CHAPTER V

CONCLUSION

The wood-polymer composites which prepared from para rubberwood impregnated with styrene-butylacrylate and styrene-acrylamide in this research can improve the physical and mechanical properties of para rubberwood. The preparation method was carried out by impregnation the rubberwood with monomers and curing the monomers with heat treatment. The optimum conditions for para rubberwood-polymer composites in this investigation were :

Benzoyl peroxide	2	phr.
Evacuating time	2	hours.
Soaking time	4	hours.

Para rubberwood-poly(styrene-co-butylacrylate) and poly(styrene-co-acrylamide) obtained under the suitable condition gave higher polymer loading and improved the properties, such as water absorption. The water absorption of WPC was reduced to about 51-72 percent and the density was increased to about 28-52 percent compared with untreated para rubberwood. Moreover, the resulting WPC gave high ant swell efficiency (ASE) and dimension stability.

However, both types of the copolymer behaved in the same trend. They gave high polymer loading, density and ant swell efficiency which resulted in the reduction of the water absorption.

For mechanical properties, modulus of elasticity, flexure stress and compression parallel to grain could be improved to about 23-51%, 24-65% and 75-

75-105%, respectively. Some mechanical properties such as modulus of elasticity and flexure stress were better than Teakwood and Redwood.

Impregnated sample with styrene-butylacrylate showed the highest values of compression at the ratio of 100:0 and the highest values of MOE, and flexure stress at the ratio of 0:100. The MOE, flexure stress and compression of sample impregnated with styrene-acrylamide were also increased. However, most samples showed improvement in mechanical properties compared to the untreated para rubberwood.

Termites resistance was carried out and compared with untreated para rubberwood, Teakwood and Redwood. The results showed that para rubberwood-polymer composites could be resistance to termites and fungi very well similar to Teakwood and Redwood.

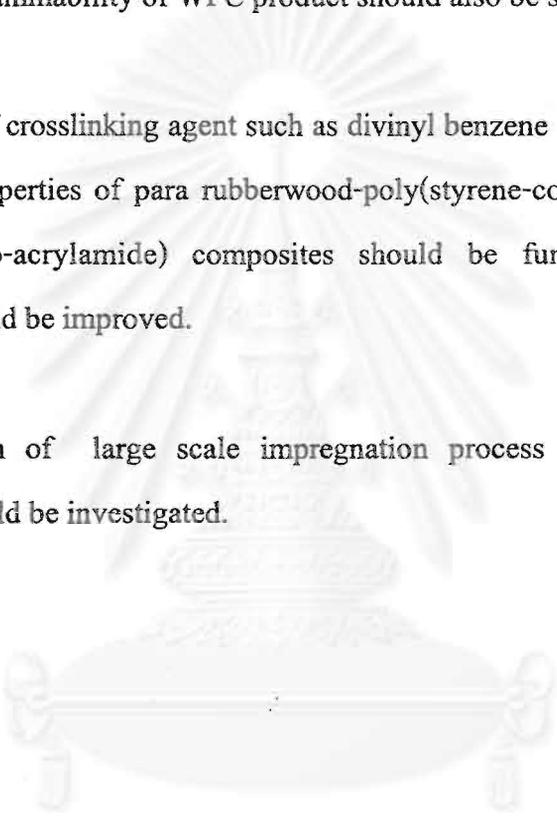
The microstructure investigation of impregnated para rubberwood showed that the lumen of wood could be fully filled with polymer compared with untreated para rubberwood and consequently resulting in the improvement of mechanical properties.

Therefore, para rubberwood-poly(styrene-co-butylacrylate) and poly(styrene-co-acrylamide) could be a potential material to replace Teakwood and Redwood in certain application such as furniture, flooring material and others.

SUGGESTIONS FOR FURTHER WORK

The wood-polymer composites should be further studied as the following

1. Other monomer types to make wood-polymer composites (WPC) such as phenol-formaldehyde and urea-formaldehyde with flame retardant properties and the effect of the impregnation on mechanical and physical properties, especially on flammability of WPC product should also be studied.
2. The effect of crosslinking agent such as divinyl benzene on the physical and mechanical properties of para rubberwood-poly(styrene-co-butylacrylate) and poly(styrene-co-acrylamide) composites should be further studied. The properties should be improved.
3. Modification of large scale impregnation process to prepare bigger specimens should be investigated.



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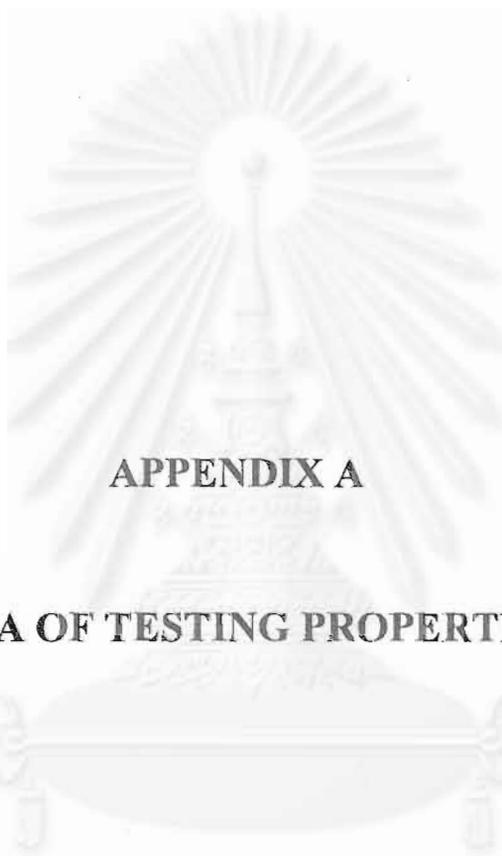
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APPENDICES

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APPENDIX A

DATA OF TESTING PROPERTIES

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Table A The parameters for preparation of para rubberwood-polymer composites

WPC	Initiator types	Initiator content (%)	Monomer ratio (%)	Evacuating time (hrs.)	Soaking time (hrs.)
A	BPO	2	100 (ST)	2	4
B	MEKPO	2	100 (ST)	2	4
C	BPO	1	100 (ST)	2	4
D	BPO	3	100 (ST)	2	4
E	BPO	2	80:20 (ST:BA)	2	4
F	BPO	2	60:40 (ST:BA)	2	4
G	BPO	2	50:50 (ST:BA)	2	4
H	BPO	2	40:60 (ST:BA)	2	4
I	BPO	2	20:80 (ST:BA)	2	4
J	BPO	2	100 (BA)	2	4
K	BPO	2	80:20 (ST:AM)	2	4
L	BPO	2	60:40 (ST:AM)	2	4

WPC	Initiator types	Initiator content (%)	Monomer ratio (%)	Evacuating time (hrs.)	Soaking time (hrs.)
M	BPO	2	50:50 (ST:AM)	2	4
N	BPO	2	40:60 (ST:AM)	2	4
O	BPO	2	20:80 (ST:AM)	2	4
P	BPO	2	100 (AM)	2	4

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Table A-1 Testing properties of natural para rubberwood

Physical properties					Mechanical properties		
Sample/piece (unit)	Moisure content (%)	Density (g/cm ³)	Water absorption (%)	Swelling Coefficient	Modulus of elasticity (MPa)	Flexure stress (MPa)	Compression (N/mm ²)
1/1	7.24	0.5960	56.36	0.0771	5127	72.6	32.00
1/2	7.57	0.6050	61.56	0.0798	6801	95.6	39.30
1/3	7.02	0.5755	60.21	0.0851	6635	100.2	39.00
1/4	7.29	0.5882	63.48	0.0885	6972	96.3	41.00
1/5	7.44	0.6244	57.13	0.0786	7601	78.0	44.00
Average	7.31	0.5978	59.75	0.0818	6627	92.6	39.06
2/1	7.46	0.6141	58.93	0.0892	7538	107.1	36.40
2/2	7.13	0.5889	56.31	0.0791	6214	84.1	49.40
2/3	7.19	0.6008	62.84	0.0925	6604	108.8	44.20
2/4	7.36	0.5930	56.90	0.0788	7203	92.4	33.50
2/5	7.08	0.6249	60.32	0.0890	5262	74.8	42.00
Average	7.24	0.6043	59.06	0.0857	6564	93.4	41.10
Average	7.28	0.6011	59.41	0.0838	6596	93.0	40.08
S.D	0.05	0.0046	0.49	0.0028	45	0.6	1.44

Table A-2 Testing properties of para rubberwood-polymer composite A

Physical properties					Mechanical properties				
Sample/piece (unit)	Polymer Loading (%)	Density (g/cm ³)	Water absorption (%)	ASE (%)	Polymer Loading (%)	MOE (MPa)	Flexure stress (MPa)	Polymer Loading (%)	Compression (N/mm ²)
1/1	45.00	0.9027	20.95	38.66	44.97	9427	123.5	40.43	88.20
1/2	46.30	0.9353	21.33	27.21	50.78	8700	149.3	46.60	99.80
1/3	55.45	0.9288	20.31	28.65	57.54	10121	155.6	47.24	79.50
1/4	40.38	0.9372	23.66	37.46	42.53	9945	144.3	44.33	85.10
1/5	48.71	0.9448	23.94	28.97	55.91	7045	129.0	53.07	100.20
Average	47.17	0.9298	22.04	32.19	50.35	9048	140.3	46.13	90.56
2/1	47.51	0.9255	23.58	36.90	47.49	9270	135.2	39.51	86.80
2/2	46.29	0.8974	22.35	33.82	53.76	8800	132.0	45.28	88.80
2/3	54.73	0.9331	20.13	28.95	50.01	8510	148.5	52.45	95.40
2/4	50.94	0.9096	21.89	27.98	59.33	10451	150.3	48.16	84.30
2/5	45.62	0.8995	22.73	35.26	54.12	8960	131.0	39.70	94.80
Average	49.02	0.9130	22.14	32.58	52.94	9198	139.4	45.02	90.02
Average	48.09	0.9214	22.09	32.39	51.64	9122	139.9	45.58	90.29
S.D	1.31	0.0119	0.07	0.23	1.83	106	0.6	0.78	0.38

Table A-3 Testing properties of para rubberwood-polymer composite B

Physical properties					Mechanical properties				
Sample/piece (unit)	Polymer Loading (%)	Density (g/cm ³)	Water absorption (%)	ASE (%)	Polymer Loading (%)	MOE (MPa)	Flexure stress (MPa)	Polymer Loading (%)	Compression (N/mm ²)
1/1	41.07	0.8948	24.97	27.99	51.07	10941	135.8	39.38	82.60
1/2	43.49	0.9022	23.48	30.46	42.17	10538	133.8	44.05	82.80
1/3	47.56	0.9135	22.68	35.58	47.98	8640	155.9	36.87	95.60
1/4	39.25	0.8912	26.84	28.63	53.19	6985	131.9	45.20	88.20
1/5	48.31	0.9142	22.25	27.18	50.41	7463	125.7	39.42	77.60
Average	43.94	0.9032	24.04	29.97	48.96	8913	136.6	40.98	85.36
2/1	46.60	0.9043	25.71	28.72	44.70	9030	142.1	38.71	83.20
2/2	44.97	0.8995	24.09	28.36	54.30	8250	129.3	42.22	96.70
2/3	38.53	0.8734	23.60	35.42	51.41	9660	138.1	36.53	90.30
2/4	45.17	0.8977	21.46	30.65	42.33	9050	135.6	39.16	78.20
2/5	48.66	0.9065	24.54	27.54	47.65	9880	140.7	49.62	97.50
Average	45.20	0.8963	23.88	30.14	48.08	9174	137.2	41.25	89.18
Average	44.57	0.8997	23.96	30.10	48.52	9044	136.9	41.12	87.27
S.D	0.89	0.0049	0.11	0.06	2.03	185	0.4	0.19	2.70

Table A-4 Testing properties of para rubberwood-polymer composite C

Physical properties					Mechanical properties				
Sample/piece (unit)	Polymer Loading (%)	Density (g/cm ³)	Water absorption (%)	ASE (%)	Polymer Loading (%)	MOE (MPa)	Flexure stress (MPa)	Polymer Loading (%)	Compression (N/mm ²)
1/1	40.82	0.8676	26.33	27.06	41.08	8926	138.1	32.50	92.20
1/2	42.14	0.8727	23.62	28.74	58.12	9236	143.5	41.08	86.40
1/3	45.67	0.9355	25.85	30.47	40.28	8152	130.4	38.34	78.00
1/4	45.93	0.9192	25.96	28.24	59.42	9117	139.8	45.51	89.60
1/5	42.86	0.8987	23.14	27.40	38.17	8928	130.6	49.13	90.60
Average	43.48	0.9047	24.98	28.38	47.41	8872	136.5	41.31	86.36
2/1	42.68	0.8943	23.96	28.70	45.87	8068	122.8	36.99	85.40
2/2	39.80	0.8766	26.15	35.44	49.19	8289	130.1	46.88	87.40
2/3	46.51	0.9211	20.95	30.53	45.43	9640	142.4	44.13	90.10
2/4	43.62	0.9071	23.99	28.61	43.33	8915	136.4	43.78	86.00
2/5	50.56	0.8824	26.97	26.52	51.51	10765	150.5	43.55	91.00
Average	44.63	0.8963	24.40	29.96	47.07	9135	136.4	43.07	87.98
Average	44.06	0.9005	24.69	29.17	47.24	9004	136.5	42.19	87.67
S.D	0.81	0.0059	0.41	1.12	0.24	186	0.1	1.24	0.44

Table A-5 Testing properties of para rubberwood-polymer composite D

Physical properties					Mechanical properties				
Sample/piece (unit)	Polymer Loading (%)	Density (g/cm ³)	Water absorption (%)	ASE (%)	Polymer Loading (%)	MOE (MPa)	Flexure stress (MPa)	Polymer Loading (%)	Compression (N/mm ²)
1/1	48.43	0.9229	21.65	38.66	56.13	7435	124.6	39.38	96.30
1/2	60.29	0.9962	18.02	27.21	43.38	8055	160.9	36.61	95.10
1/3	54.61	0.9527	19.89	28.65	49.57	10177	141.9	57.07	84.00
1/4	48.21	0.9083	21.21	37.46	64.44	10520	142.6	48.15	92.00
1/5	47.50	0.9101	22.13	28.97	47.95	9449	128.0	42.93	90.20
Average	51.81	0.9380	20.58	32.19	52.29	9127	139.6	44.83	91.52
2/1	43.79	0.9311	22.45	35.59	53.71	8848	133.2	56.04	92.90
2/2	52.12	0.9049	18.39	29.40	45.06	9640	148.6	47.12	100.00
2/3	48.44	0.9855	24.62	31.45	57.45	9636	155.6	45.90	80.40
2/4	57.13	0.9016	18.30	31.13	46.90	8915	136.4	40.73	90.60
2/5	49.35	0.9280	20.76	29.76	58.64	8449	129.3	38.96	95.00
Average	50.17	0.9302	20.90	31.47	52.35	9098	140.6	45.75	91.78
Average	50.99	0.9341	22.74	31.83	52.32	9112	140.1	45.29	91.65
S.D	1.16	0.0055	0.23	0.51	0.04	21	0.6	0.65	0.18

Table A-6 Testing properties of para rubberwood-polymer composite E

Physical properties					Mechanical properties				
Sample/piece (unit)	Polymer Loading (%)	Density (g/cm ³)	Water absorption (%)	ASE (%)	Polymer Loading (%)	MOE (MPa)	Flexure stress (MPa)	Polymer Loading (%)	Compression (N/mm ²)
1/1	41.67	0.8794	23.52	36.99	49.00	9848	143.2	48.07	90.50
1/2	51.95	0.8846	22.78	34.46	53.07	9603	138.8	45.31	90.60
1/3	59.34	0.9363	19.61	36.63	45.99	9133	136.9	38.80	88.50
1/4	42.96	0.9324	20.17	34.70	55.93	9051	148.4	49.06	70.60
1/5	44.16	0.8753	24.45	38.29	44.14	11123	139.8	39.71	93.60
Average	48.02	0.9017	22.11	36.21	49.63	9752	141.4	44.19	86.76
2/1	55.35	0.9370	21.22	38.72	50.00	9981	144.4	49.00	84.40
2/2	50.42	0.9044	21.66	35.46	53.19	8745	132.9	44.25	87.40
2/3	42.78	0.8665	16.89	32.42	45.74	9087	151.9	35.51	83.20
2/4	46.15	0.8919	17.68	34.65	49.74	11122	149.8	42.93	95.10
2/5	49.34	0.8924	22.90	38.94	52.74	9751	140.3	46.45	86.00
Average	48.81	0.8984	20.07	36.02	50.28	9737	143.8	43.63	87.22
Average	48.41	0.9001	21.09	36.12	49.96	9745	142.6	43.91	86.99
S.D	0.56	0.0023	1.44	0.13	0.46	11	1.4	0.40	0.33

Table A-7 Testing properties of para rubberwood-polymer composite F

Physical properties					Mechanical properties				
Sample/piece (unit)	Polymer Loading (%)	Density (g/cm ³)	Water absorption (%)	ASE (%)	Polymer Loading (%)	MOE (MPa)	Flexure stress (MPa)	Polymer Loading (%)	Compression (N/mm ²)
1/1	45.34	0.9237	20.39	37.08	49.48	9734	151.4	47.77	88.70
1/2	51.58	0.9313	20.21	34.75	50.00	10280	155.8	39.12	83.00
1/3	52.44	0.9321	19.29	32.47	50.47	8915	136.4	38.64	75.40
1/4	44.56	0.9061	21.59	41.24	60.67	8484	141.2	41.09	80.40
1/5	48.18	0.9100	19.05	35.47	47.64	9640	142.4	61.15	82.80
Average	49.42	0.9206	20.11	36.20	51.65	9411	145.4	45.55	82.06
2/1	44.39	0.9460	18.65	40.72	55.61	8778	148.2	41.02	83.20
2/2	58.44	0.9226	20.20	42.55	48.72	9514	156.3	49.70	78.20
2/3	42.52	0.9003	22.47	39.54	65.39	9185	140.1	58.31	78.60
2/4	49.91	0.9125	23.61	35.82	42.81	10080	152.9	36.19	88.00
2/5	49.82	0.9384	20.06	37.62	50.78	8692	144.7	40.09	90.30
Average	49.02	0.9220	20.99	39.25	52.66	9250	147.8	45.06	83.66
Average	49.22	0.9213	20.55	37.71	52.16	9330	146.6	45.31	82.86
S.D	0.23	0.0010	0.62	2.16	0.71	114	1.7	0.35	1.13

Table A-8 Testing properties of para rubberwood-polymer composite G

Physical properties					Mechanical properties				
Sample/piece (unit)	Polymer Loading (%)	Density (g/cm ³)	Water absorption (%)	ASE (%)	Polymer Loading (%)	MOE (MPa)	Flexure stress (MPa)	Polymer Loading (%)	Compression (N/mm ²)
1/1	44.54	0.9309	18.65	42.58	46.81	10286	149.2	39.79	74.20
1/2	49.92	0.9009	20.50	32.68	60.84	9949	156.4	40.29	84.20
1/3	41.34	0.9305	18.98	34.46	45.10	9306	128.4	44.27	73.80
1/4	48.22	0.9429	16.25	38.04	56.67	10828	166.5	44.44	79.40
1/5	58.93	0.9191	19.44	37.13	55.34	8606	145.2	45.00	77.60
Average	48.59	0.9249	18.76	36.98	52.95	9795	149.1	42.76	77.84
2/1	49.78	0.9212	21.22	30.32	55.61	9656	155.6	45.07	90.60
2/2	53.60	0.9324	21.66	31.15	48.72	9765	148.1	42.96	65.00
2/3	51.45	0.9171	17.89	43.88	65.39	9778	148.5	50.63	71.20
2/4	48.62	0.9561	20.68	40.23	42.81	10245	150.7	39.02	77.20
2/5	45.98	0.8998	22.90	37.13	50.78	9385	149.6	41.15	81.20
Average	49.89	0.9253	20.87	36.54	52.66	9766	150.5	43.77	77.04
Average	49.74	0.9251	19.82	36.76	52.81	9780	149.8	43.26	77.44
S.D	0.92	0.0003	1.49	0.31	0.21	21	1.0	0.71	0.57

Table A-9 Testing properties of para rubberwood-polymer composite H

Physical properties					Mechanical properties				
Sample/piece (unit)	Polymer Loading (%)	Density (g/cm ³)	Water absorption (%)	ASE (%)	Polymer Loading (%)	MOE (MPa)	Flexure stress (MPa)	Polymer Loading (%)	Compression (N/mm ²)
1/1	49.26	0.9025	20.83	35.60	42.77	10712	159.2	41.33	82.80
1/2	43.46	0.8761	25.72	29.88	51.35	10209	145.5	49.45	78.80
1/3	55.71	0.9341	18.64	36.27	50.26	10645	154.8	53.44	65.20
1/4	48.62	0.8955	21.14	33.49	51.46	9797	153.4	35.43	75.40
1/5	49.59	0.9306	20.65	34.74	49.70	10512	149.8	37.50	75.60
Average	49.33	0.9078	21.40	33.97	49.11	10375	152.5	43.43	75.56
2/1	49.17	0.9240	19.86	37.00	49.72	10277	152.2	49.01	78.60
2/2	46.61	0.8884	23.32	30.06	53.08	8951	150.8	44.25	69.40
2/3	51.32	0.9383	19.71	36.13	44.18	9793	161.3	35.51	64.20
2/4	47.25	0.9063	21.60	34.09	55.93	8827	141.5	42.92	79.20
2/5	48.89	0.9165	20.92	34.91	46.82	10765	150.5	46.45	80.70
Average	48.65	0.9147	21.08	34.44	49.95	9723	151.3	43.63	74.42
Average	48.99	0.9113	21.24	34.20	49.53	10049	151.9	43.53	74.99
S.D	0.48	0.0049	0.23	0.33	0.60	376	0.7	0.14	0.81

Table A-10 Testing properties of para rubberwood-polymer composite I

Physical properties					Mechanical properties				
Sample/piece (unit)	Polymer Loading (%)	Density (g/cm ³)	Water absorption (%)	ASE (%)	Polymer Loading (%)	MOE (MPa)	Flexure stress (MPa)	Polymer Loading (%)	Compression (N/mm ²)
1/1	48.09	0.9099	21.25	34.26	50.77	9715	154.3	42.31	68.80
1/2	41.84	0.9235	24.87	27.15	51.15	9630	155.6	38.93	70.40
1/3	51.15	0.9272	20.12	36.69	49.54	11513	160.9	36.27	71.70
1/4	55.79	0.9441	19.70	42.76	45.82	9849	157.4	47.46	71.90
1/5	46.18	0.9061	22.62	37.21	49.56	10087	151.7	35.27	67.80
Average	48.61	0.9222	21.71	35.61	49.37	10159	155.9	40.05	70.12
2/1	47.73	0.9322	21.59	43.81	52.01	10229	165.1	43.06	73.00
2/2	56.29	0.9567	20.76	35.37	47.74	11071	159.7	42.48	68.20
2/3	52.18	0.9479	23.30	44.60	50.86	9513	155.4	38.55	69.00
2/4	45.35	0.9147	19.88	40.62	45.82	11486	154.8	47.63	69.40
2/5	49.61	0.9230	21.17	31.21	54.71	8551	140.8	41.91	74.90
Average	50.23	0.9348	21.34	39.12	50.23	10170	155.2	42.72	70.90
Average	49.52	0.9286	21.53	37.37	49.80	10165	155.3	41.39	70.51
S.D	1.15	0.0089	0.26	2.48	0.61	6	0.4	1.89	0.55

Table A-11 Testing properties of para rubberwood-polymer composite J

Physical properties					Mechanical properties				
Sample/piece (unit)	Polymer Loading (%)	Density (g/cm ³)	Water absorption (%)	ASE (%)	Polymer Loading (%)	MOE (MPa)	Flexure stress (MPa)	Polymer Loading (%)	Compression (N/mm ²)
1/1	50.45	0.9247	19.01	36.92	54.60	10277	152.2	44.00	58.80
1/2	59.20	0.9640	16.41	42.57	53.80	11291	177.3	39.49	60.20
1/3	54.61	0.9342	17.56	40.66	52.05	9976	165.2	40.82	60.60
1/4	49.30	0.9263	18.91	38.19	47.75	9224	153.3	42.13	64.40
1/5	45.79	0.8996	20.21	36.84	48.48	9920	150.5	48.04	58.00
Average	51.00	0.9298	18.42	39.04	51.34	10138	159.7	42.90	60.40
2/1	54.22	0.9668	19.62	35.32	42.47	10174	171.7	43.06	69.20
2/2	48.47	0.8916	19.83	36.12	46.71	9892	150.8	42.47	71.30
2/3	48.62	0.9308	18.04	40.31	46.78	9550	151.6	38.55	62.60
2/4	53.47	0.9462	19.26	38.62	55.24	9650	160.3	47.63	67.40
2/5	50.35	0.9233	20.72	38.09	56.59	9470	156.1	41.91	59.50
Average	51.03	0.9317	19.49	37.69	49.56	9747	158.1	42.72	66.00
Average	51.00	0.9308	18.96	38.37	50.45	9943	158.9	42.81	63.20
S.D	0.02	0.0013	0.76	0.95	1.26	226	0.9	0.13	3.96

Table A-12 Testing properties of para rubberwood-polymer composite K

Physical properties					Mechanical properties				
Sample/piece (unit)	Polymer Loading (%)	Density (g/cm ³)	Water absorption (%)	ASE (%)	Polymer Loading (%)	MOE (MPa)	Flexure stress (MPa)	Polymer Loading (%)	Compression (N/mm ²)
1/1	36.18	0.8576	27.14	27.82	33.96	8570	133.2	35.15	79.50
1/2	30.83	0.8209	31.59	27.66	35.44	10800	130.5	28.31	79.00
1/3	34.63	0.8016	28.49	25.73	39.47	8761	135.3	35.87	78.60
1/4	27.06	0.8048	30.00	24.91	32.06	10563	129.7	33.51	80.80
1/5	33.33	0.8259	27.63	27.08	40.06	8385	129.5	32.05	90.40
Average	32.41	0.8222	28.97	26.64	36.20	9416	131.6	32.78	81.66
2/1	30.61	0.8348	27.76	26.34	39.28	9561	132.9	32.49	81.40
2/2	35.77	0.8263	30.32	24.46	35.07	8068	122.8	34.71	80.40
2/3	28.52	0.7969	32.96	25.35	31.23	8796	131.2	32.31	85.30
2/4	29.36	0.8026	29.83	26.10	36.83	9050	128.6	28.19	80.20
2/5	33.88	0.8405	31.60	24.23	33.40	9385	139.2	28.01	84.20
Average	31.63	0.8202	30.49	25.30	35.16	8972	130.9	31.14	8230
Average	32.02	0.8212	29.73	25.97	35.68	9194	131.3	31.96	81.98
S.D	0.55	0.0014	1.07	0.95	0.60	256	0.4	0.95	0.37

Table A-13 Testing properties of para rubberwood-polymer composite L

Physical properties					Mechanical properties				
Sample/piece (unit)	Polymer Loading (%)	Density (g/cm ³)	Water absorption (%)	ASE (%)	Polymer Loading (%)	MOE (MPa)	Flexure stress (MPa)	Polymer Loading (%)	Compression (N/mm ²)
1/1	20.83	0.7433	27.25	26.92	27.83	8827	129.5	27.51	77.90
1/2	21.98	0.7750	32.12	31.48	26.60	9952	132.0	25.34	71.60
1/3	24.41	0.7453	31.72	26.73	22.53	7541	120.5	24.22	74.00
1/4	21.23	0.7180	34.87	30.20	25.97	8595	123.1	18.21	78.20
1/5	24.84	0.7964	29.43	25.67	24.43	8190	122.7	24.43	76.80
Average	22.66	0.7556	31.08	28.20	25.47	8621	125.6	23.94	75.70
2/1	24.85	0.7860	38.37	24.80	24.21	8544	120.2	21.78	77.20
2/2	22.18	0.7486	29.28	29.09	29.76	8045	122.9	25.03	74.00
2/3	26.74	0.7805	35.91	25.78	25.45	8039	129.3	22.46	75.40
2/4	21.79	0.7064	27.93	29.45	22.08	8905	131.3	18.87	70.90
2/5	22.17	0.7882	30.21	28.83	21.22	10201	121.1	24.21	73.20
Average	23.55	0.7619	32.34	27.59	24.54	8747	125.0	22.47	74.14
Average	23.11	0.7588	31.71	27.90	25.01	8684	125.3	23.21	74.92
S.D	0.51	0.0036	0.89	0.43	0.54	73	0.3	0.85	0.90

Table A-14 Testing properties of para rubberwood-polymer composite M

Physical properties					Mechanical properties				
Sample/piece (unit)	Polymer Loading (%)	Density (g/cm ³)	Water absorption (%)	ASE (%)	Polymer Loading (%)	MOE (MPa)	Flexure stress (MPa)	Polymer Loading (%)	Compression (N/mm ²)
1/1	18.81	0.6699	36.43	25.39	21.96	8223	128.3	20.94	72.20
1/2	19.03	0.7002	30.81	28.54	21.03	8486	117.6	19.37	73.90
1/3	21.14	0.7476	29.88	32.61	20.96	7865	124.2	15.71	67.30
1/4	15.48	0.6736	37.20	23.27	19.60	7991	119.7	17.03	69.60
1/5	23.87	0.7393	30.63	25.78	19.61	7807	123.8	23.63	71.00
Average	19.67	0.7061	32.99	27.12	20.63	8074	122.7	19.34	70.80
2/1	15.20	0.6821	31.83	26.37	20.24	7637	121.4	17.45	71.90
2/2	23.60	0.7630	31.96	24.89	14.78	7789	118.1	17.20	67.80
2/3	18.45	0.7212	34.60	24.25	22.33	6681	116.7	17.79	70.40
2/4	18.77	0.7497	28.62	31.18	20.08	9061	118.8	21.31	73.00
2/5	15.16	0.7265	29.16	22.83	18.15	8617	130.4	18.98	70.20
Average	18.24	0.7285	31.23	25.90	19.12	7957	121.1	18.55	70.66
Average	18.95	0.7173	32.11	26.51	19.87	8016	121.9	18.94	70.73
S.D	7.77	0.2758	1.24	0.86	8.34	3195	57.2	29.82	0.08

Table A-15 Testing properties of para rubberwood-polymer composite N

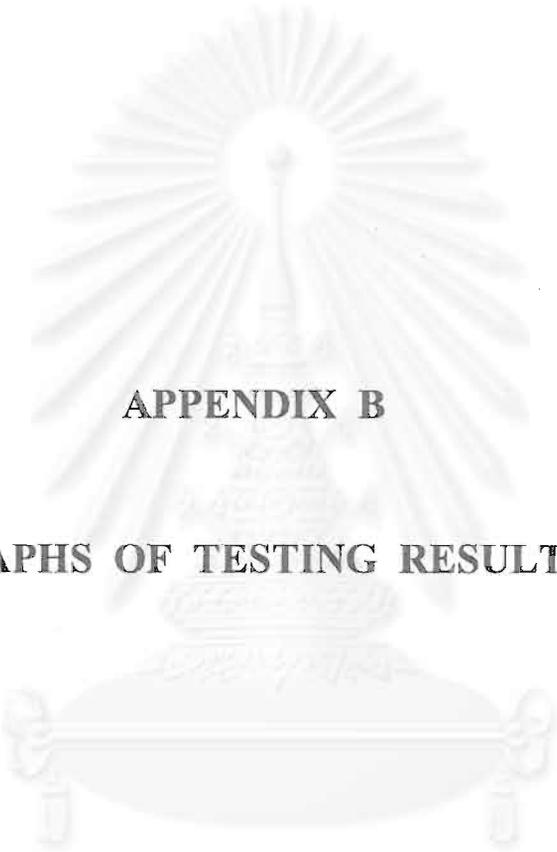
Physical properties					Mechanical properties				
Sample/piece (unit)	Polymer Loading (%)	Density (g/cm ³)	Water absorption (%)	ASE (%)	Polymer Loading (%)	MOE (MPa)	Flexure stress (MPa)	Polymer Loading (%)	Compression (N/mm ²)
1/1	16.51	0.7182	33.75	28.04	20.00	9068	116.8	19.70	73.20
1/2	15.42	0.6689	33.00	27.88	19.83	6833	128.4	15.00	71.00
1/3	15.53	0.6958	37.74	23.65	19.72	7986	117.6	15.39	63.50
1/4	20.26	0.7132	35.42	24.76	14.31	7865	124.2	12.54	68.30
1/5	13.14	0.6716	32.01	25.47	15.05	7476	120.7	19.72	62.40
Average	16.17	0.6935	34.38	25.96	17.78	7846	121.5	16.47	67.68
2/1	18.81	0.7041	36.26	23.16	19.81	8260	124.9	15.91	63.10
2/2	16.16	0.7228	32.79	27.43	15.72	7588	122.4	18.02	69.50
2/3	16.29	0.7039	35.28	24.61	17.39	7800	118.9	20.95	71.50
2/4	14.43	0.6560	33.08	24.25	14.90	6681	112.7	16.09	64.40
2/5	12.05	0.6662	33.15	25.07	15.44	8265	121.5	12.28	62.70
Average	15.55	0.6906	34.11	24.90	16.65	7719	120.1	16.65	66.24
Average	15.86	0.6921	34.25	25.43	17.22	7782	120.8	16.56	66.96
S.D	0.36	0.0017	0.19	0.75	0.65	73	0.8	0.10	0.83

Table A-16 Testing properties of para rubberwood-polymer composite O

Physical properties					Mechanical properties				
Sample/piece (unit)	Polymer Loading (%)	Density (g/cm ³)	Water absorption (%)	ASE (%)	Polymer Loading (%)	MOE (MPa)	Flexure stress (MPa)	Polymer Loading (%)	Compression (N/mm ²)
1/1	20.06	0.7608	30.08	25.47	22.84	8176	122.2	21.76	71.90
1/2	19.85	0.7280	33.11	26.34	15.20	7053	118.9	14.72	68.20
1/3	16.68	0.6884	38.71	19.88	13.35	6203	111.3	17.14	70.60
1/4	22.64	0.7195	30.22	27.61	20.53	7895	116.8	20.46	76.00
1/5	15.97	0.6959	34.66	24.18	19.05	9029	122.6	13.16	59.90
Average	19.04	0.7158	33.35	24.70	18.19	7671	118.4	17.45	69.32
2/1	17.32	0.7441	33.96	25.60	20.88	7619	115.8	15.01	69.40
2/2	19.46	0.7532	33.61	26.34	22.08	8561	118.8	16.12	68.40
2/3	17.19	0.6916	33.15	25.76	11.48	6681	111.7	18.25	70.50
2/4	16.84	0.7340	35.40	23.28	20.35	8265	121.5	14.93	69.40
2/5	17.28	0.7366	32.52	23.92	20.26	8020	117.5	20.40	72.80
Average	17.62	0.7319	33.33	24.98	19.01	7829	117.1	16.94	70.10
Average	18.33	0.7252	33.34	24.84	18.60	7750	117.8	17.20	69.71
S.D	0.82	0.0114	0.01	0.20	0.47	91	0.8	0.29	0.22

Table A-17 Testing properties of para rubberwood-polymer composite P

Physical properties					Mechanical properties				
Sample/piece (unit)	Polymer Loading (%)	Density (g/cm ³)	Water absorption (%)	ASE (%)	Polymer Loading (%)	MOE (MPa)	Flexure stress (MPa)	Polymer Loading (%)	Compression (N/mm ²)
1/1	23.01	0.7611	26.96	34.06	25.66	7483	118.9	23.42	70.50
1/2	27.62	0.7635	26.81	34.98	23.65	7029	116.6	24.35	72.20
1/3	26.38	0.7074	29.27	31.55	23.25	8113	112.5	25.84	72.70
1/4	27.05	0.8002	25.88	35.19	24.42	9721	113.5	27.83	76.90
1/5	21.31	0.8498	29.57	30.70	22.58	7775	118.0	21.31	67.20
Average	25.07	0.7764	27.70	33.30	23.91	8024	115.9	24.55	71.90
2/1	25.92	0.7491	29.53	35.66	23.75	8619	115.8	29.80	78.30
2/2	23.96	0.7662	25.77	31.78	22.91	7948	116.2	25.05	74.00
2/3	25.58	0.7059	28.26	39.06	28.57	8265	121.5	24.21	68.00
2/4	22.46	0.7806	27.50	32.54	22.16	7006	112.4	21.91	63.60
2/5	27.05	0.7494	25.43	35.82	21.19	7547	108.5	24.20	67.20
Average	24.99	0.7502	27.30	34.97	23.72	7877	114.9	25.03	70.22
Average	25.03	0.7633	27.50	34.14	23.81	7951	115.4	24.79	71.06
S.D	0.05	0.0151	0.28	1.18	0.11	104	53.8	0.28	30.23



APPENDIX B

GRAPHS OF TESTING RESULTS

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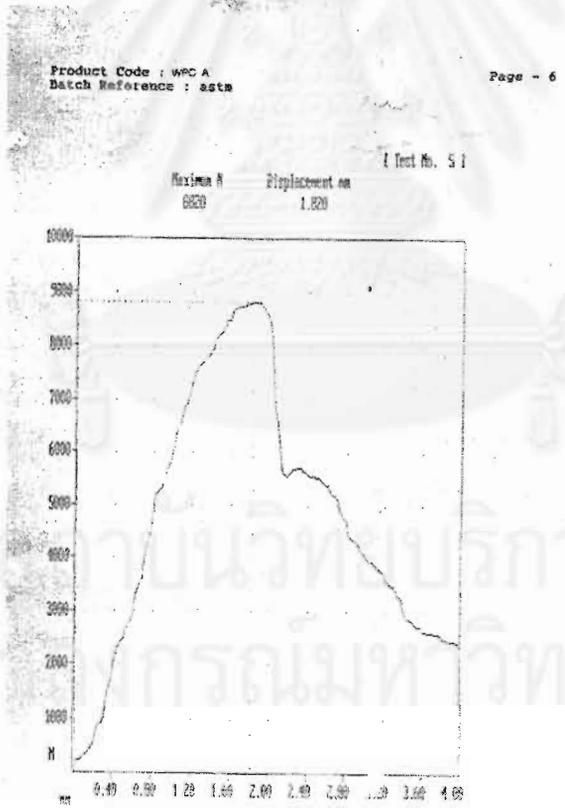
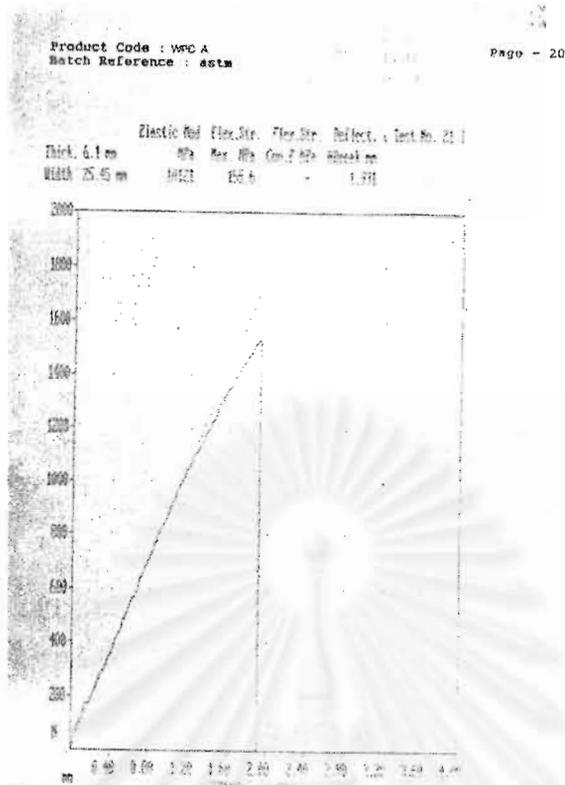


Figure B-1 Graphs of MOE, flexure stress (above figure) and compression testing (bottom figure) of wood-polymer composites A

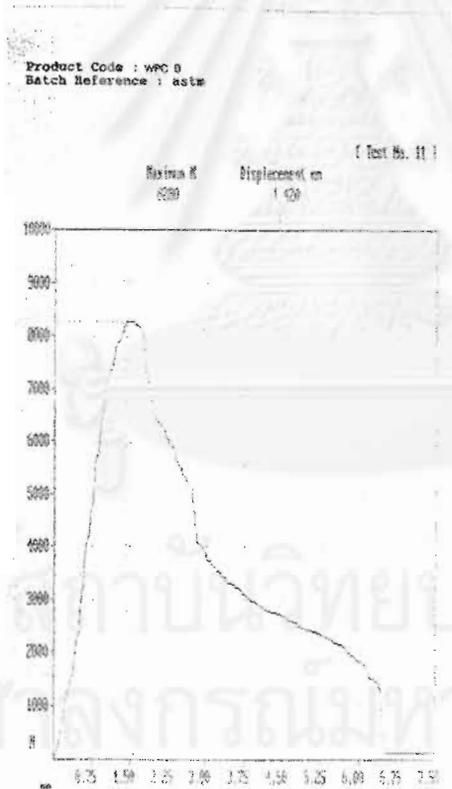
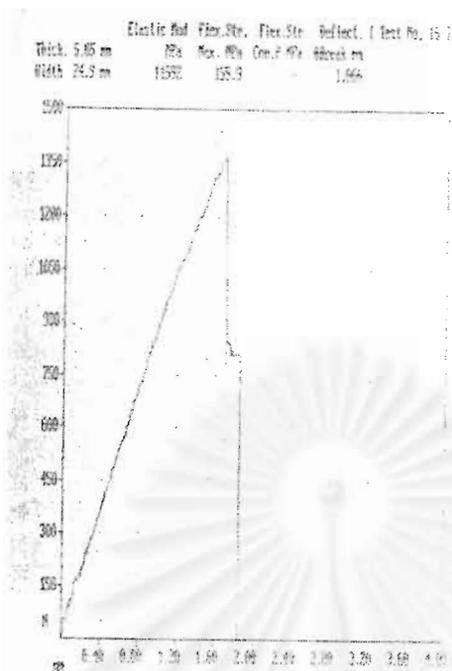
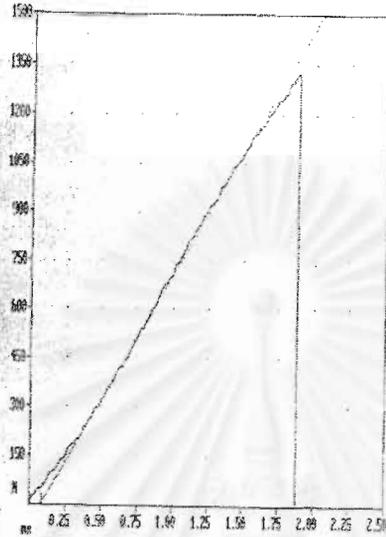


Figure B-2 Graphs of MOE, flexure stress (above figure) and compression testing (bottom figure) of wood-polymer composites B

Product Code : WPC C
 Batch Reference : astm

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Elastic Mod Flex.Stre. Flex.Stre. Deflect. (Test No. 9)
 Thick. 6.12 mm Mod. Max. MPa Com.P MPa @break mm
 Width 25.77 mm 6209 138.1 1.269



Product Code : WPC C
 Batch Reference : astm

Page -

Elastic Mod Flex.Stre. Flex.Stre. Deflect. (Test No. 10)
 Thick. 6.28 mm Mod. Max. MPa Com.P MPa @break mm
 Width 25.95 mm 2005 122.8 1.826

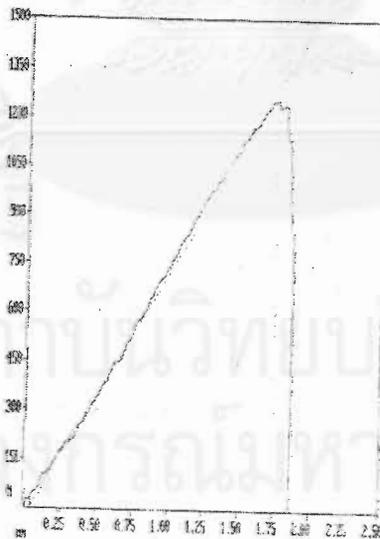
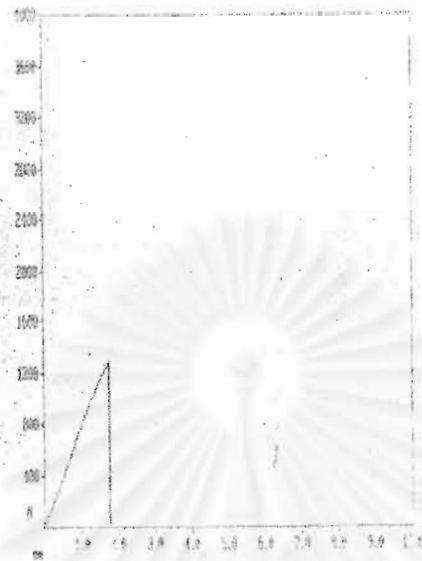


Figure B-3 Graphs of MOE, flexure stress (above figure) and compression testing (bottom figure) of wood-polymer composites C

Product Code : WPC D107
 Batch Reference : astm

Product Code	Flex Str.	Flex Str.	Deflect.	Test No.
WPC D107	1630	1050	1.754	12



Product Code : WPC D
 Batch Reference : astm 3501

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Maximum of	Displacement mm	(Test No. 12)
1630	1.754	

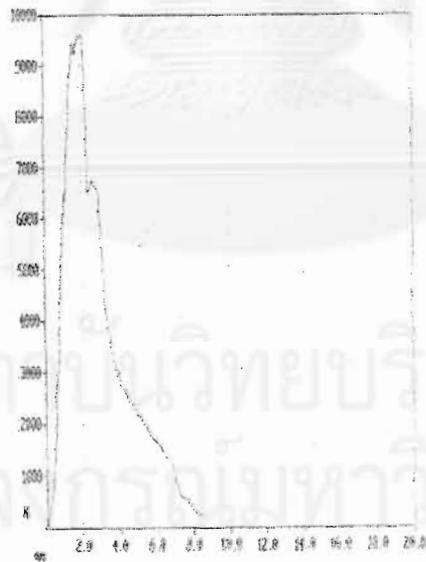


Figure B-4 Graphs of MOE, flexure stress (above figure) and compression testing (bottom figure) of wood-polymer composites D

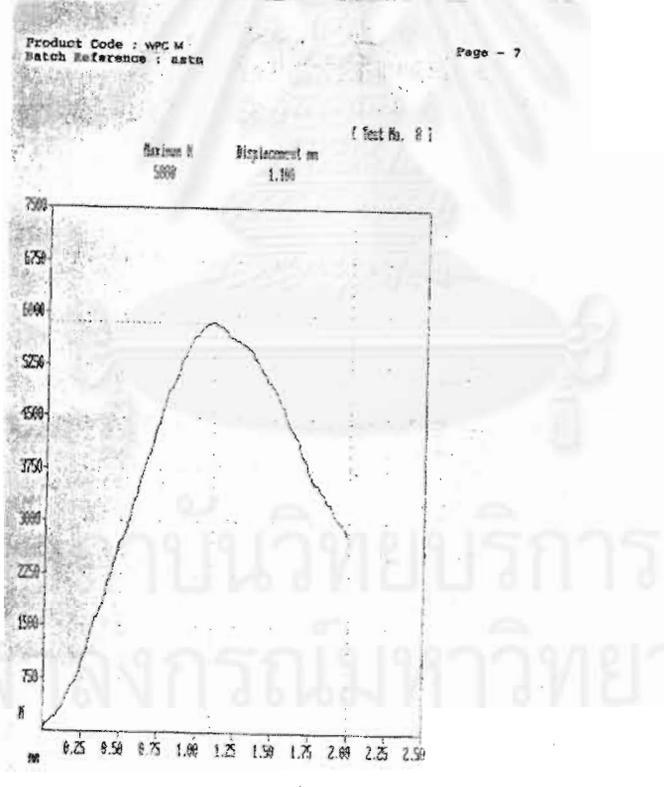
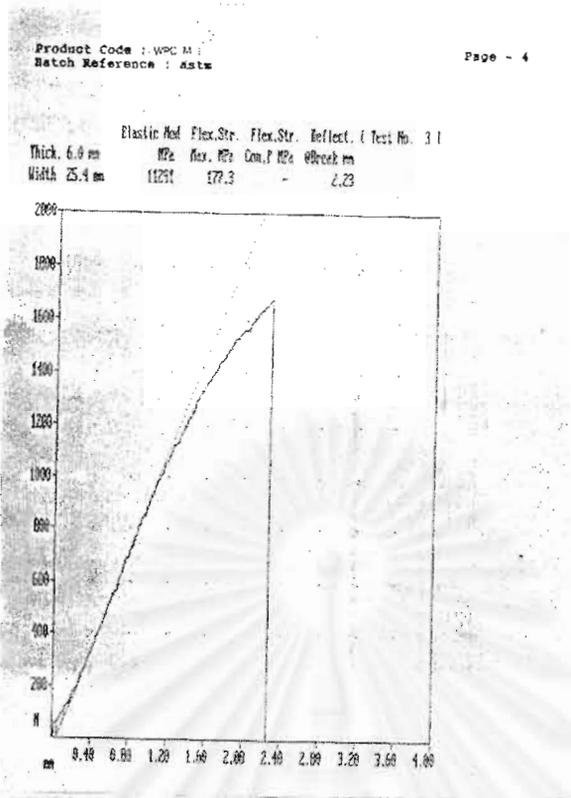


Figure B-5 Graphs of MOE, flexure stress (above figure) and compression testing (bottom figure) of wood-polymer composites J

VITA

Miss Ausana Sukhonphanich was born on February 18, 1977, in Ratchaburi province, Thailand. She received her Bachelor of Science degree in Chemistry, from Chulalongkorn University in 1999. Since 1999, she has been a graduate student in the Program of Petrochemistry and Polymer Science, Faculty of science, Chulalongkorn University, and completed her Master of Science degree in 2001.



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