ไม้ยางพารา-เอพอกซีเรซิน คอมโพสิต

นางสาว เชลงจิตร รุ่งวิชานิวัฒน์

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PARA RUBBERWOOD-EPOXY RESINS COMPOSITES

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งานวิจัยนี้เป็นการศึกษาการเตรียมไม้ยางพารา-เอพอกซีเรซิน คอมโพสิต ด้วยวิธีทำไม้ยางพาราให้ชุ่มด้วยเอพอกซี เรซินพรีพอลิเมอร์ภายใต้การลดความดัน โดยศึกษา ผลของชนิดตัวเจือจาง ปริมาณสารเชื่อมโยงที่มีผลต่อความหนืดและเวลาที่ใช้ในการเกิดการเชื่อมโยงของส่วนผสมพรีพอลิเมอร์ รวมทั้งศึกษาภาวะที่เหมาะสมของกระบวนการเตรียมตัวอย่าง เช่น เวลาที่ใช้แช่ชิ้นตัวอย่างในส่วนผสม เวลาและความดันที่ใช้ดึงอากาศออกจากช่องว่างในเซลล์ไม้ โดยแปรเปลี่ยนค่าเหล่านั้นให้แตกต่างกันในการเตรียมแต่ละตัวอย่าง และศึกษาผลกระทบที่มีต่อสมบัติความเสถียรทางขนาดและสมบัติทางกลของตัวอย่างที่เตรียมขึ้น เปรียบเทียบกับไม้ยางพาราธรรมชาติ

ผลการศึกษาพบว่า ตัวเจือจางชนิดว่องไว ในปริมาณ 30 ส่วนต่อเรซิน 100 ส่วนและปริมาณตัวเชื่อมโยง 27 ส่วนต่อเรซิน 100 ส่วน ในส่วนผสมพรีพอลิเมอร์มีความเหมาะสมกับการเตรียมตัวอย่าง และภาวะที่เหมาะสมเป็นดังนี้ คือ เวลาที่ใช้ในการแช่ชิ้นตัวอย่าง 1 ชั่วโมง เวลาที่ใช้ดึงอากาศออกจากช่องว่างในเซลล์ไม้ 2 ชั่วโมง และความดันที่ใช้ดึงอากาศออกจากเซลล์ไม้คือ 500 มิลลิเมตรของปรอท ตัวอย่างไม้ยางพารา-เอพอกซีเรซิน คอมโพสิต ที่เตรียมขึ้นจากสภาวะดังกล่าว มีสมบัติความเสถียรทางขนาด คือการดูดซับน้ำที่ต่ำกว่าไม้ยางพาราธรรมชาติมาก สมบัติทางกล คือ มอดูลัสยืดหยุ่น ความทนแรงบิดงอ การทนต่อแรงอัด ถูกปรับปรุงดีขึ้น และความถ่วงจำเพาะมากขึ้น เมื่อเปรียบเทียบกับไม้ยางพาราธรรมชาติ

ภาควิชา –

สาขาวิชา ปิโตรเคมีและวิทยาศาสตร์พอลิเมอร์

ปีการศึกษา 2542

ลายมือชื่อนิสิต

ลายมือชื่ออาจารย์ที่ปรึกษา

ลายมือชื่ออาจารย์ที่ปรึกษาร่วม –

4073409223 : MAJOR POLYMER SCIENCE
KEY WORD: PARA RUBBERWOOD / EPOXY RESIN / COMPOSITE / HARDENER / DILUENT / IMPREGNATION
CHALENGJIT RUNGVICHANIWAT : PARA RUBBERWOOD-EPOXY RESINS COMPOSITES.
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This research involves the preparation of 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 mixture were studied. Impregnation conditions such as soaking times, evacuating time, evacuating pressure were varied to various conditions in the preparation process. Dimensional stability and mechanical properties of impregnated samples were compared with natural para rubberwood.

Results of this study showed that 30 phr reactive diluent and 27 phr hardener content were suitable for impregnating prepolymer mixture into para rubberwood matrix. The optimum preparation conditions were 1 hour soaking time, 2 hours evacuating times and 500 mmHg evacuating pressure. Para rubberwood-epoxy resins composites obtained form these conditions gave significant lower water absorption, higher antishrink efficiency than natural para rubberwood. Modulus of elasticity, flexure stress, compression parallel to grain were improved and specific gravity was higher than natural para rubberwood.

ภาควิชา - **ลายมือชื่อนิสิต**

สาขาวิชา ปิโตรเคมีและวิทยาศาสตร์พอลิเมอร์ **ลายมือชื่ออาจารย์ที่ปรึกษา**

ปีการศึกษา 2542 **ลายมือชื่ออาจารย์ที่ปรึกษาร่วม** -

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CONTENTS

CONTENT(Continued)

CONTENT(Continued)

LIST OF TABLES

TABLE PAGE

LIST OF FIGURES

LIST OF FIGURES(Continued)

LIST OF ABBREVIATIONS

ANRPC	Asia natural rubber producing countries
ASE	Antishrink efficiency
°C	Degree celsius
cps	Centripoise second
DEGBA	Diglycidyl ether of bisphenol A
g	gram
gm/cc	gram per cubic meters
g/eq	gram per equivalent
Kg/L	Kilogram per liter
mmol/Kg	millimole per kilogram
mmlb	metric million pound
MOE	Modulus of elasticity
MC	Moisture content
MPa	Mega pascal
N/mm^2	Newton per square millimeter
NR	Natural rubber
Pas	Pascal second
phr	Part per hundred resin
PL	Polymer loading
Pt-Co	Platinum-Cobalt
SEM	Scanning electron microscopy
Sp.gr.	Specific gravity
WA	Water absorption
WPC	Wood-polymer composites

CHAPTER 1

INTRODUCTION

Wood, as a renewable resource, has provided persons with tools, weapons, and shelter since the beginning of our coexistence on this planet. During the millennium of our development we learned how to make wood harder and stronger by drying and heat-tempering our wooden tools and weapons. As our knowledge of the world we lived increased, we attempted other modification to better fit our increased requirements. Treatment of wood to modify its properties has two objectives: dimensional stabilization due to moisture content and improvement in physical and mechanical characteristics [1].

1.1 Introduction to Rubberwood

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 soured from effluents and waste from rubber processing and above all rubber timber is now a valuable resources. Over the last decade the demand for rubber timber had been increasing rapidly. The term, " rubberwood" is usually given to the timber of the species *Hevea brasiliensis*.[2]

The good working qualities of rubber timber, 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.

The total growing area of natural rubber (NR) in Asia natural rubber producing countries (ANRPC) in 1994 was about 7.87 million hectares. Table 1.1 shows the planted area in 1994 in the member countries. The estimated area replanted in 1994 is given in Table 1.2

Table1.1 Growing area of NR in ANRPC countries 1994 (X1000 hectares)

Country	Area
India	516
Indonesia	3,448
Malaysia	1,760
Sri Lanka	192
Thailand	1,940

Table1. 2 Area replanted in 1994 (X1000 hectares)

Country	Area
India	7.5
Indonesia	39.2
Malaysia	30.0
Sri Lanka	1.6
Thailand	37.0

Assuming the yield of wood from rubber trees at 180 cubic meters per ha. The potential output of rubberwood from these countries in 1994 would add up to 20.75 million cubic meters. Again, based on the usual assumption that 180 cubic meters of rubberwood would result in 45 cubic meters of usable logs the potential output of usable logs in 1994 would be 5.2 million cubic meters. At prices of about US $ 2.3 cubic meters, the value of usable logs in 1994 from the ANPRC countries would have been the region of US $ 119.6 million. The above calculation is based on estimated area of replant.[5]

Wood consumption in Thailand was about 4 million cubic meters in 1992 of which only about 110,000 cubic meters was produced domestically. The balance was imported. Thailand exported furniture parts valued at 16,738 million Bahts ($ 661.8 million) in 1993 and the figure for 1994 was 19,530 million Bahts ($ 779.6 million), representing an increase of less than 17 %. A sizable portion of the furniture parts were made from rubberwood. Rubberwood could be expected to meet a major part of the future need in Thailand.

Rubberwood, despite its valuable properties, is known to display undesirable properties, such as poor dimensional stability toward moisture absorption. The moisture in wood also affects decay resistance and mechanical properties. Thus, treatment of wood to improve its dimensional stability and mechanical properties by making wood polymer composite could be the way to solve these problems.

1.2 Objective of the Research Work

1.To study the para rubberwood–epoxy resins composites prepared by impregnation para rubberwood with resin under reduced pressure.

2.To study the dimensional stability, mechanical properties of para rubberwood- epoxy resins composites obtained under various conditions.

1.3 Scopes of the research work

In this research work, the wood–polymer composites was prepared from epoxy resins prepolymer mixtures and para rubberwood by impregnating under reduced pressure process. Suitable prepolymer mixture and various impregnation conditions such as diluent types and content, hardener content, soaking time, evacuating time, and evacuating pressure were investigated. The dimensional stability and mechanical properties of specimens such as polymer loading, modulus of elasticity, water absorption, flexure stress, antishrink efficiency, compression parallel to grain, specific gravity, and SEM of microstructure figure were studied.

CHAPTER 2

THEORY AND LITERATURE REVIEW

Treatment of solid wood with many chemical systems that affected the cell wall and filled the void space in the wood is the basis for altering physical and chemical properties of wood. Some of these treatments find commercial applications, while some remain laboratory curiosities. A brief descriptions of the earlier treatments is given for heat-stabilized wood, phenol formaldehyde-treated veneers, bulking of the cell wall with polyethylene glycol, ozone gas-phase treatment, ammonia liquid and gas phase treatment, and β- and γ- radiation. Many of these treatments led to commercial products, such as Staybwood, Staywood, Impreg, and Compreg. Generally wood-polymer implies bulk polymerization of a vinyl type monomers in the void space of solid wood. This bulk polymerization takes place in vessels, capillaries, ray cells etc., but not in the cell wall or middle lamella. The monomer is introduced into the solid wood by vacuum process. The wood-monomer is then converted into the solid polymer by γ-radiation or a heat – sensitive catalyst dissolved in the monomer. Finally, the wood-polymer is fabricated into the final product [1].

2.1 Formation and structure of wood

2.1.1 Wood sources

Wood is obtained from two broad categories of plants known commercially as softwoods and hardwoods. These names cannot be used universally to refer to the actual physical hardness or density of all woods because some soft wood are quite hard and some hard wood are soft.

From a more scientific perspective, softwoods are tree species of a class of plant called gymnosperms (seeds are borne naked and hardwoods are woody, dicotyledonous (two seed leaves) angiosperms (seeds are borne in a fruit structures).

The softwoods are also referred to conifers because they produce seed cones, pollen cones, or both. The conifers have needlelike or scalelike leaves and appear to be evergreen in that they retain new leaves for several years.

Hardwoods have leaves that are generally board or bladelike, and many commercial species in temperate climates- are deciduous, which means they commonly shed their leaves each fall at the end of the tree's growing season.

2.1.2 Technical nature

Wood is a complex plant tissue composed of several district types of cells. In their fully mature state, the vast majority of wood cells are dead and hollow, and the resulting tissue known technically as secondary xylem is composed essentially of only cell walls and voids. The voids are being the hollow interiors of the cells (or lumens) as shown in Figure 2.1. In softwoods, the cells making up 90–95 % of wood volume are fibrous in form and are thus termed fibers. Hardwoods, on the other hand, are composed largely of fibers and much wider cells called vessel elements. The vessel elements are joined end-wise to form tubes or vessels along the stem, branch or root axis and are seen as pores on the wood cross section.

From a chemical perspective, wood tissue (including cells and inter cellular substance) is a composites material constructed from a variety of organic polymers. The basic structural or skeletal materials of all wood cell wall is cellulose, hemicelluloses and lignins.

The wood cell wall – cellulose and hemicellulose – have a strong affinity for water molecules in either their liquid or vapor state. Lignin on the other hand, is almost water repelling.

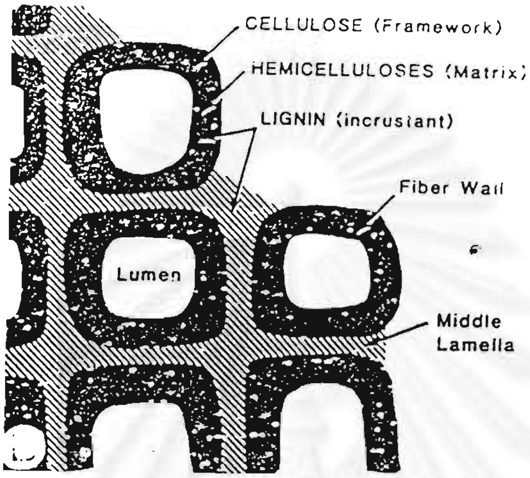


Figure 2.1 Schematic showing the location of major constituents of wood [1].

2.1.3 Wood cell production

The site of wood cell production is the vascular cambium. It is responsible for the manufacture of all initial and subsequent wood tissues. The cambium is a thin, circumferential sheat of cells that produces wood or secondary xylem to the inside (i.e. toward the tree center) and pholem or inner bark tissue to the out side. Xylem functions largely in upward conduction and mechanical support, and pholem acts as a conduct for downward movement of photosynthases (manufactured foodstuffs) and hormones from leaves and buds. Both xylem and pholem also function in a storage capacity. which takes place largely in parenchyma cells [1].

All cells in cambium zone are living cell. However, as xylem derivatives(i.e., developing wood cells) begin a sequence of transformations that will convert them into mature wood elements, they embark on a path of cell specialization or differentiation that will lead eventually to cell death.

New xylem derivatives may function for a period of time as mother cells, diving to form other derivatives. Nevertheless, the ultimate fate of most xylem derivatives is self destruction, autolysis, of their living contents, protoplast, and the eventual products are fully differentiated, or specialized, wood cells possessing rather elaborate walls and hollow centers, lumens. Only a relatively small number of cells in wood called parenchyma retain a visible protoplast after exiting the cambial and differentiation zones.

Parenchyma are small, nonfibrous cells that have special storage on secretory functions. It also compose most (or all in hardwoods) of the wood tissue regions referred to collectively as wood rays. These structures are narrow ribbons of cells that are oriented lengthwise along the tree radius and perpendicular to the stem axis (Figure 2.2)

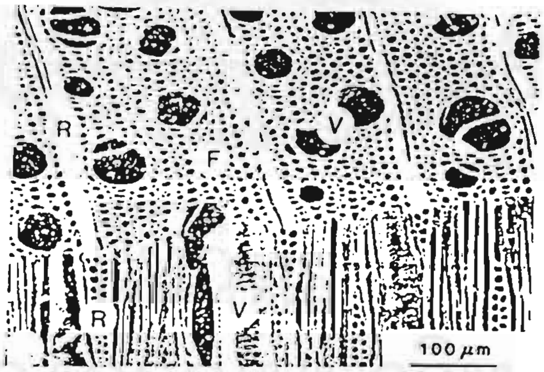


Figure 2.2 SEM of wood rays (R) ,vessel or pores (V),and wood fiber(F) [1].

During the division and enlargement phases of wood cell development, the cell wall is thin, deformable, and extensible envelope of material referred to as the primary wall. Near the cessation of cell enlargement, however, a secondary wall may begin to be manufactured to the lumen side of the primary wall. Wood fibers, vessel elements, and certain other xylem or pholem elements that function in passive conduction, and/or support normally develop a secondary wall (Figure 2.3)

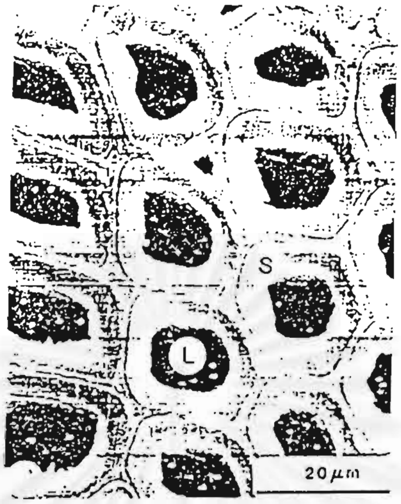


Figure 2.3 Cross-sectional view of fully differentiated wood fibers. The thin cell wall (S) and fiber lumen (L) [1].

2.1.4 Hardwoods

Hard woods contain a substantial volume of fiber cells, but the distinguishing feature of angiosperm xylem is occurrence of vessels. The vessels are seen on the wood cross section as holes or pores in various patterns (Figure 2.4). Thus, all hardwoods are also referred to as porous wood [1].

An individual vessel or pore consists of a vertical series of short vessel segments, which are joined end to end along the grain. Individual vessels can meander to a limited extent in radial or tangential direction to join, terminate in, or depart from other vessels, but their major function is the vertical translocation of sap. To facilitate this translocation, the ends of all vessel segments are peforate, that is, the ends are open for free flow of liquids between cells. In some hardwoods the vessel segment ends are entirely open (simple), while in others ends contain a series of parallel crossbars(scalariform) or some other design. The particular type of opening here is of considerable value in wood species identification.

Hardwood fibers, because of the presence of vessels, occupy a proportionally smaller volume of wood tissue than softwood fibers do. The fiber themselves are also smaller. The parenchyma cell content of hardwoods is, on the average, much greater than that of softwoods. This situation is a result of the wider rays and greater ray volume of hardwoods and also the relatively high proportion of longtitudinal parenchyma.

The volume ratio of vessels to fibers and fiber wall thickness are two important factors influencing the hardness and density of different hardwood species and the permeability of these woods to liquids and gases. Wood grain is also party a function of these two parameters.

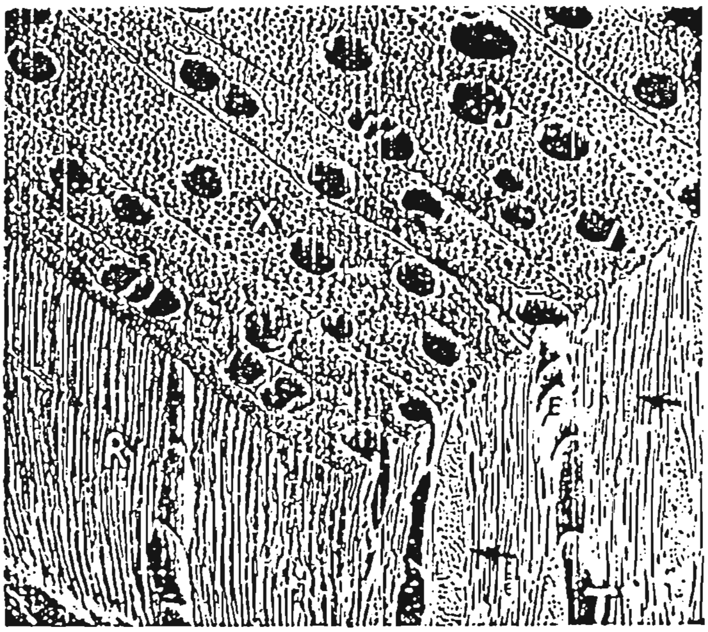


Figure 2.4 Diffuse-porous hardwood, formation of vessels from individual vessel elements(E), in radial(R) and tangential (T) views [3].

2.2 Rubberwood

2.2.1 Technical properties and utilization of rubberwood

The most important product of the rubber tree is the latex and all efforts to improve the rubber tree have been from the point of obtaining higher yield of latex. After exploitation, the rubber tree is felled for replanting with high yielding clones. Till recently, most of the wood from the felled trees was used as fuel. With the depletion of forests in many parts of tropical regions, leading to shortage of wood for many industrial and engineering uses, attention has been given to rubber wood as an alternative source of timber. Research and development activities on the industrial applications of rubberwood are only of recent origin. New developments indicate the possibility of wider use of rubberwood for a variety of purposes [4].

Rubber trees grow to a height of 25 meters and generally have straight trunks. Usually, at the time of felling, the girth varies between 100 to 110 centimeters, at a height of 125 centimeters above the ground and gives 0.62 cubicmeters of stump wood and 0.40 cubicmeters of branch wood. At the time of felling, usually it contains 180 to 185 trees per hectare.

2.2.2 Anatomy of Rubberwood

The texture of the wood is fairly even with moderately straight and slightly interlocking grain. From whitish yellow when freshly cut, the wood turns to light brown as drying progresses. 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 half-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.[4] .

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.

2.2.3 Physical and Mechanical Properties

Like all other wood species, rubber wood also exhibits orthotropicity in its properties, i.e., its properties are different and independent in the three principal direction 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. The strength in dry condition (i.e. below the fibre saturation point) varies according to the formula [4] as follows:

$$\log S = a - bm$$

Where S = strength at moisture content m

m = moisture content of the piece of wood in question – average value

a,b = constants relating to the property

For most of the mechanical properties of rubber wood $a = 2.5$, $b = 0.015$ when S is unknown and its density 'd' is known, the strength is given by the formula

$$S = Kd^n$$

Where K and n are constants depending upon the strength property. In the case of most of the strength properties in both green and dry conditions $n = 1$, but otherwise it is found to vary between 0.75 and 2.5. Similarly K varies from 163 to 1665 in the green condition and from 140 to 1854 in the dry condition.

Like most of the wood species, the dynamic properties of rubber wood (i.e. mechanical behavior of rubber wood under dynamic forces) are higher than the static properties. In other words, under impact loads, rubber wood is capable of taking loads nearly twice that under slowly applied loads. However, it may be noted that the static properties of rubber wood 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.

Physical and mechanical properties of Para Rubberwood, *Hevea brasiliensis* Muell.Agr. (Euphorbiaceae) are shown in Table 2.1.

Table 2.1 Physical and mechanical properties of para rubberwood.

Green	Unit	Green	Air dry	Oven dry
Number of annual ring	per inch	5	5	5
Specific gravity	gm /cc.	0.58	0.60	-
Shrinkage ratio				
Radial	-	-	1.31	2.55
Tangetial	-	-	1.53	5.20
Volumetric	-	-	5.11	8.60
Static bending	Kg / cm^3			
Modulus of rupture		535	887	-
Modulus of elasticity		68,700	93,500	-
Fibre stress at elastic limit		334	550	-
Compression // to grain	Kg / cm^2			
Maximum crushing strength		283	438	-
Compression $\perp$ to grains	Kg / cm^2			
Crushing proportional limit		34	94	-

2.3 Methods for improve dimensional stability of wood

All methods for attaining improved dimensional stability of wood fall into one or more of five different types [5].

1.Laminating of anisotropic sheets so as to restrain the dimensional changes of one sheets that swell less in this direction, as in plywood.

2.Applying water-resistant surface and internal coating to retard moisture adsorption or loss.

3.Reducing the hygroscopicity of the cellulose materials, thus reducing water adsorption and swelling.

4.Bulking the fiber so as to reduce the amount of water that the component fibers can hold.

5.Cross-linking the cellulose chains of the component fiber so that their separation by water adsorption is minimized.

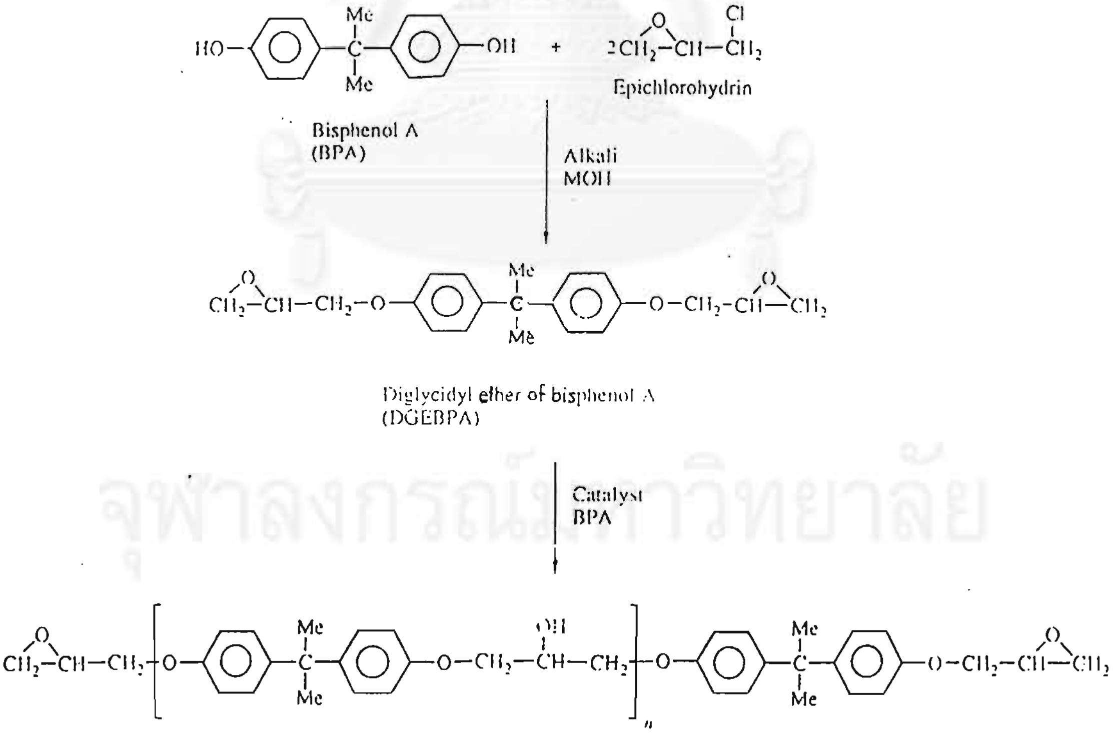
2.4 Resin treatments.

It would be better to put a water-soluble material into the cell walls followed by converting it to a water-insoluble material in situ. Aqueous solutions of several different thermosetting resin-forming systems were tried with considerable success. Phenol formaldehyde resin, using an alkaline catalyst, meets the requirements that had the advantage over the raw mix in that it is less volatile and very small amounts are lost when the water is removed by drying prior to curing of the resin and has further advantages in that it swells wood about 25 percent beyond the swelling in water, thus further opening up the structure so that, after cure of the resin, close to the normal water swollen volume of the wood is obtained [5].

The other synthetic resin that is used commercially as a bulking nsio abilizing agent for wood at the present time is furfural alcohol, resorcinal alaldehyde and melamine formaldehyde might be used to advantage in some cases if they were cheaper. Epoxy resins probably deserve some consideration as wood bulking impregnants.

2.4.1 Epoxy Resins

The word 'epoxy resins' is meant to both the prepolymers and to the cured resins. The previous one contains reactive epoxy groups. In the cured resins all of the reactive groups may have reacted, so that although they no longer contains epoxy groups the cured resins are still called epoxy resins. The earliest epoxy resins commercially available were the reaction products of bisphenol A and epichlorohydrin and this is still the major route for the manufacture of most of the resins marketed today, although there are many types of resin available [6].



The major application of epoxy resins is still for surface coatings, which consumes about 50 % of all epoxy resins produced. The relative application of epoxy resins is indicated in Table 2.2.

Table 2.2 Applications of epoxy resins (Modern Plastics International, 1992) [6].

	[1990]		[1991]	
	1000 tonnes	%	1000 tonnes	%
Protective coating	89	49	84	51
Electrical applications	25	14	22	13
Reinforced resins	14	7.5	13	8
Bonding and adhesives	13	7.5	12	7.25
Flooring	12	6.5	11	6.25
Tooling and casting	13	7.5	12	7.25
Other	15	8.3	12	7.25
Total	181	100.3	166	100.00

Epoxy resins are usually more expensive than their rivals such as phenolic resins for coatings or laminates. Therefore epoxy resins find application because of their superior properties, which include both processing and those of the cured resin. The processing is convenient since it is possible to formulate compositions with the required rheological properties, such as low viscosity and there is also a wide choice of hardeners so that it is possible to cure at ambient as well as elevated temperatures. Because epoxy resins can be cross-linked without the formation of low molecular weight products, volatiles are not evolved during cured and the resins have only a relatively low shrinkage during curing. Their mechanical and electrical properties are superior to other resins and they have good heat and chemical resistance.

2.4.2 Hardener

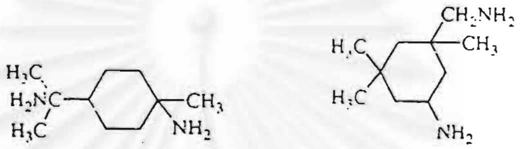
Originally only a relatively few types were known and this included le amines, acid anhydrides, phenol-formaldehyde and amino-formaldehyde resins. Nowadays there is an extended selection available and there are two reasons for the growth. Firstly, as alternative types of epoxy resin were developed so was the potential for other organic chemicals to function as curing agents recognised. This led to the introduction of polyfunctional amines, polybasic carboxylic acids, mercaptans and even inorganic chemicals .Secondly and consecutively with end application development for epoxy systems there has been a need to modify available curing agents to meet specific ultimate requirements - hence the comprehensiveness of the speciality curing agent manufacturers ranges. Table 2.3 describes the estimated relative world market usage in 1989 for the commercially moat significant curing agent types [6].

Table 2.3 Estimated world market for curing agents by type [6].

	Weight (mmlb)	Relative use (%)
Amines - aliphatics	45	10
- cycloaliphatics	30	7
- aromatics	15	3
- dicyandiamide	10	2
Polyamides	75	16
Polyamidoamines	30	7
Phenol-and amino-formaldehyde resins	75	16
Carboxylic acid functional polyesters	100	22
Anhydrides	55	12
Polysulphides and polymercaptans	15	3
Catalysts	10	2

2.4.2.1Cycloaliphatic polyamines

1,8 -Methane diamine was one of the first cycloaliphatic polyamines be considered for heat cured epoxy applications. This highly hindered di-primary amine prepared by hydrocyanation of the terpenes or limonene is low in viscosity provides long working – lives and gives high heat and chemical resistance 3–aminomethy–3,5,5 trimethylcyclohexylamine commonly known as Iso Phorone Diamine (IPDA) has however been most widely adopted as the industry standard cycloaliphatic amine [6].



1,8-Menthane diamine

IsoPhoroneDiAmine (IPDA)

Figure 2.6 Chemical structure of cycloaliphatic polyamine [6].

The low viscosity, light color, excellent heat resistance and cured mechanical strength mean that in unmodified form IPDA is particularly useful for small-medium size casting, filament winding electrical and general applications. The differential reactivity resulting from the presence of primary aliphatic and cycloaliphatic amine functionality content allows selective adduction with epoxy resin and selective formylation / Mannich base formation. This result in low viscosity, activated derivatives suitable for room temperature curing high performance coatings and civil engineering application [6].

The simplest modification approach involves blending the cycloaliphatic polyamine with an accelerator and a plasticising diluent. Accelerators which can be used include aliphatic polyamines, simple tertiary amines and organic acids. The most used plasticising diluent particularly in combination with the most used provides a weak accelerating effect and helps the hindered amine get through the B-stage. Applications for this low viscosity curing agent type include highly filled screed flooring and coating applications. Ciba Co.Ltd. found a further useful method of modifying cycloaliphatic amines involving partial pre-reaction with epoxy resin coupled with addition of plasticisers such as benzyl alcohol to reduce the brittleness and lower the viscosity.

2.4.3 Diluents

Diluents are usually employed as a mean of reducing viscosity in order to aid general processability as well as allowing for greater incorporation of other formulatory ingredients such as fillers and as a means of improving characteristics such as wetting and incorporation of resins into various fibrous reinforcements [6].

In addition to viscosity, it is important to recognize that other properties will also modified. The properties in question and the magnitude of modification depend on both the type and quantity of diluent employed. In addition, many of the materials capable of exerting diluent effects possess adverse toxicological characteristics, in many cases being more severe than those found with both resin and curative. Great care should therefore be taken in both selection and use.

Diluents that have been considered for use in epoxy resin technology can be divided into two broad classes comprising those which can be considered as either non – reactive or reactive.

2.4.3.1 Non –reactive diluents

A number of materials which can be regarded as non-reactives have been considered and used to provide viscosity reduction in epoxides. These include aromatic hydrocarbons such as toluene or xylene which are capable of reducing viscosity in a simple diglycidylether of bisphenol A (DEGBA) resin system sufficient to permit a room temperature viscosity approximately 20 % of its initial value with a diluent loading of about 5 %. When employed at this level, studies have shown that the level of impact on physical and mechanical properties are not usually dramatic, indeed in some cases the presence of diluent has been shown to increase the extent of cure in the formulation, presumably through the reduction in viscosity providing a reaction medium more conductive to molecular mobility and thus reactivity. At higher concentrations however, the properties of the cured epoxy can deteriorate markedly and, due to their non reactivity, diluents of this type can lead to the presence of voids in the cured polymer, primarily if the formation is subjected to elevated temperature cure sufficient to allow vaporisation of the diluent[6].

Other non- reactive material which have been considered as potential diluents include dibutyl phthalate, styrene and various phenolic compounds.

Because the compound are not chemically bound into the cross-linked network, therefore, cured formulation containing these materials usually exhibit inferior chemical resistance. Consequently, attempts at viscosity reduction with epoxides have generally made use of materials capable of chemical reaction with the epoxy resin, these generally being referred to as reactive diluents.

2.4.3.2 Reactive diluents

Two major classes of reactive diluent can and have been utilized commercially, these being either epoxy – containing diluents or compounds which derive their reactivity from functional groups other than epoxide[6].

Epoxy – based reactive diluents

Two types of diluent can be considered under this classification:

1) Mono – epoxy compounds
2) Di / Polyfunctional epoxy compounds

In both classes,the presence of the epoxide group (s) allows the diluent to participate with the resin and curing agent in the polymerization and cross-linking reaction. Thus permits the diluent to become chemically bound into the cross-linked network. Thus, to a degree, the use of reactive diluents can alleviate some of the debilitating effects found with the non – reactive compounds. Figure 2.7 shows some monoepoxy reactive diluents.

Although capable of exerting a substantial viscosity - reducing effect, these materials essentially reduce the functionality of the reaction system leading to a decrease in the cross-link density of the cured formulation. Consequently important physical and mechanical properties are frequently affected, particularly the ability to exert a high temperature capability.

The extent to which both cured properties and initial viscosity are reduced will be a function of both diluent type and concentration as shown in Figure 2.8 [4]. Thus choice of both parameter will clearly be crucial in order to derive the greatest reduction of viscosity with minimal cost to other properties

Allyl glycidyl ether

Glycidyl ester of *tert*-carboxylic acid

Figure 2.7 Chemical structure of some monoepoxy reactive diluents [6].

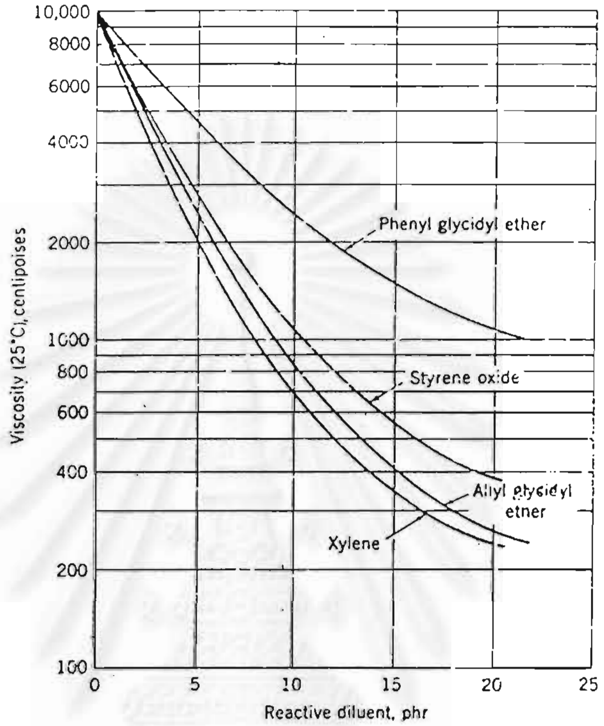


Figure 2.8 Diluent concentration vs. viscosity for DGEBA [6]

2.5 Impregnation process

Evacuating the air from the wood vessels and cell lumens carries out the first step in the impregnation of wood. Any type of mechanical vacuum pump is adequate if it can reduce the pressure in the apparatus to 750 mm of mercury or less. Experience has shown that the air in cellular structure of most woods is removed as fast as the pressure in the evacuation vessel is reduced. The vacuum pump is isolated from the system at this point.

The monomer or prepolymer containing cross-linkers as well as catalyst, and on occasion dyes, is introduced into the evacuated chamber through a reservoir at atmospheric pressure. The wood must be weighted so that it dose not float in the monomer solution. A surge tank 10 times the volume of the treating vessel is included in the system to allow the air dissolved in the monomer to expand without greatly changing the pressure in the impregnation vessel. Alternatively the system can be pumped as the monomer is admitted into the evacuated vessel. After the wood is covered with monomer solution, atmospheres pressure is regained. Immediately the monomer solution begins to flow into the evacuated wood structure to fill the void spaces. Care must be taken to maintain enough monomer solution above the wood so that air is not readmitting to the cell structure.

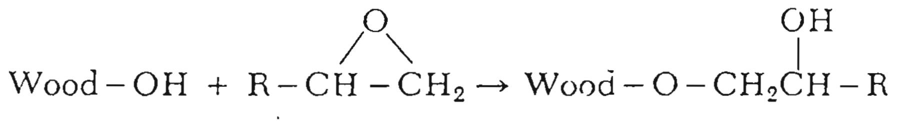
The soaking period like the evacuation period depends upon the structure of wood: maples, birch and other open–celled woods fill in about 30 minutes, other woods require longer periods of times. After the monomer impregnation is complete the wood – monomer is removed, placed in an explosion–proof oven, for curing.

2.6 The chemicals used for modifying wood

The chemicals must be capable of swelling the wood to facilitate penetration and must react with the cell wall polymer hydroxyl groups under neutral or mild alkaline condition at temperature at or below 120 °C. The chemicals should react quickly with the hydroxyl groups to yield stable chemical bonds with no by products. Chemicals used to modify wood include anhydrides, acid chlorides, lactones, nitriles and epoxides.

2.6.1 Epoxides

The reaction between epoxides and hydroxyl groups is a base-catalyzed reaction. Figure 2.9 shown the reaction between epoxides and wood.



$$\text{Wood}-\text{OH} + \text{R}-\overset{\text{O}}{\overbrace{\text{CH}-\text{CH}_2}} \rightarrow \text{Wood}-\text{O}-\text{CH}_2\overset{\text{OH}}{\overset{|}{\text{C}}}\text{H}-\text{R}$$

Figure 2.9 The reaction between epoxides and hydroxyl groups of wood

The simplest epoxide, ethylene oxide, catalyzed with trimethylamine, has been used as a vapor-phase treatment. At a weight gain of 20%, there is a 60% antishrink efficiency (ASE). An ASE of 82% with a weight gain of 10 % for the same process or with propylene oxide has been claimed also. Under similar conditions, a weight gain of 22% gives less than 1% tangential and radial shrinkage. By using an oscillating pressure rather than a constant pressure system with ethylene oxide and trimethylamine, ASE of 42 % is found for a weight gain of 11 %.

More work with propylene oxide, butylene oxide and epichlorohydrin shows an ASE of 70 % at weight gains of 22-25%. If NaOH is used with ethylene oxide in vapour treatment, extensive swelling results which causes bursting of wood structure. As with the methyl isocyanate system, high weight grains with propylene and butylene oxide, causes the ASE to fall. For propylene oxide, the maximum ASE (60-70%) is attained at weight grains between 25 and 33 %. For butylene oxide, wide range of maximum ASE values is observed: 60 –73% ASE for weight grain between 21 and 33%. The difference between this two examples may cause by the greater hydrophobicity of butylene oxide and the difference molecular weights. Both treatments showed a downward trend in ASE above 33 % weight grain as shown in Figure 2.10.

In the case of the epoxy system, after the initial reaction with a cell wall hydroxyl group, a new hydroxyl group originating from the epoxide is formed. Form this new hydroxyl, a polymer begins to form. The ionic nature of the reaction and the availability of alkoxyl ions in the wood components probably produce chain transfer, thereby yielding a short chain length. The formation of a polymer in the cell wall may be the cause of cell wall rupture at high chemicals weight gains. At a weight gain of approximately 20% the volume of the treated wood is equal to the original untreated green wood volume. Where the weight gain is more than about 30%, the volume of the treated wood is greater than that of green wood. This is the level where the antishrink efficiency (ASE) starts to drop, which may mean the polymer loading are now so high they have broken the cell wall and allowed the wood to superswell above the green wood volume. The simple epoxides are sensitive to moisture levels in the wood during reaction.

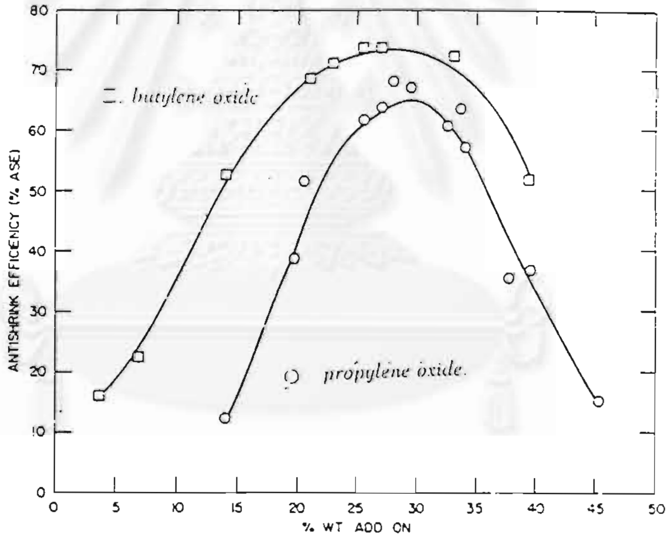


Figure2.10 Relationship between antishrink efficiency (ASE) and chemical add-on cause by epoxide modification.

2.7Water and polymer location.

The mechanism of water absorption by dry wood proceeds in two steps. Water entering dry wood in vapor form is absorbed into the cell wall, and hydrogen bonds to the cellulose. As a result, the cell wall swells, and the overall dimensions of the wood increase. After 25-28% of the water is absorbed (based on the oven-dry weight of the wood) and the cell wall has swollen to its maximum, additional water will be condensed in the capillaries or other void spaces in the wood until it is filled. The fiber-saturation point is where the cell walls have absorbed the maximum amount of water and are swollen to the maximum extent, but no water has condensed in the capillaries. Normal wood-polymer material contains polymer only in the void spaces that are available, and little if any in the cell walls. This loading of the capillary vessels reduces the rate of water diffusing into the cell walls. But, given enough time (10-20 fold greater than in untreated wood) at high humidity, eventually water will reach the cell walls and caused the same volume swelling as untreated wood. Figure2.11 and 2.12 show the differences in water absorption in WPC [7].

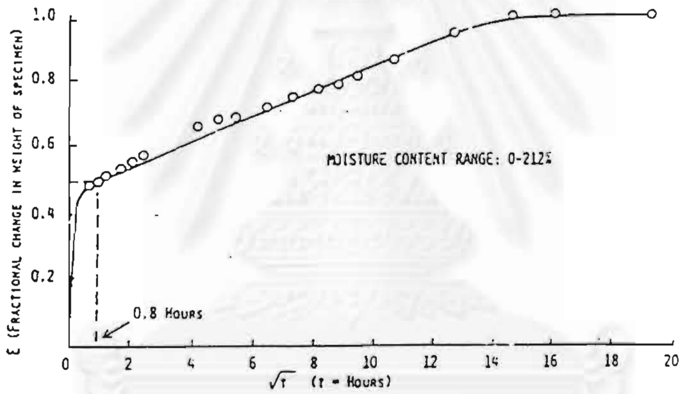


Figure 2.11 Fraction of total weight change vs.time for untreated wood.

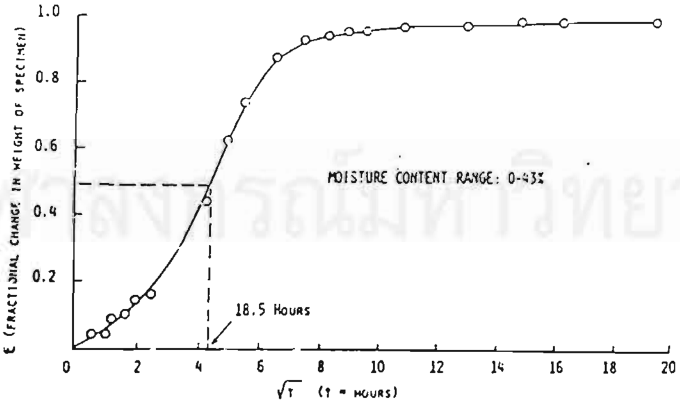


Figure 2.12 Fraction of total weight change vs. time for basswood treated with tert-butylstyrene.

2.8 Physical properties of wood

Wood, when dry, has unique physical properties in that its tensile strength, bending strength, compression strength, impact resistance, and hardness per unit weight are the highest of all construction materials. The hydrogen bonding, the unique helical structure of the cell walls, the combination of the linear cellulose molecules impregnated with low molecular weight extractives, and all of the varying amounts of cross-linked lignin make wood an infinitely resource. All the unusual features of wood are the reaction for the "art" of wood treatment.

The polymer loading of wood depends not only on the permeability of wood species, but also on the particular piece of wood being treated. Because the void volumes is approximately the same for the sapwood and heartwood of each species, it would be expected that the polymer would filled them to the same extent. However, there are exceptions, the heartwood probably has less of the voids filled with polymer because of organic deposits and tyloses that block the penetration of the monomer into the capillaries. Figure 2.13 illustrates typical test data for compression parallel to the grain for wood-polymer composites.

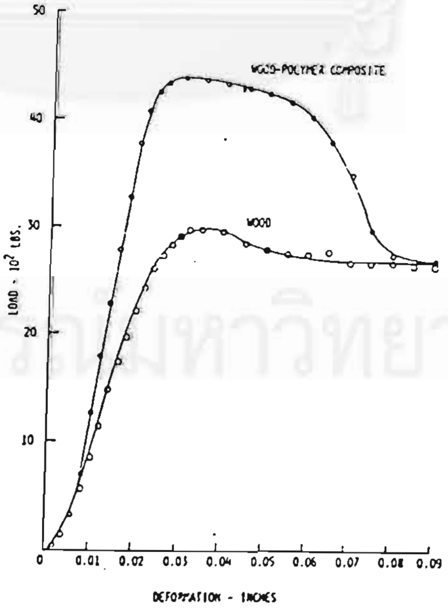


Figure 2.13 Example of typical compression test data.

Langwig [7] used difference monomers to make wood-polymer composites. These same monomers were diluted with solvents in order to obtain partial loading of the wood. In addition to MMA, tert-butylstyrene and a Heilman-Gulf epoxy monomer were used. The monomer were diluted with 50 % methanol and acetone. Dimethyl sulfoxide at 0.5% level was used as transport medium to carry the monomer into the cell wall structures. Figure 2.14 shows the result of hardness tests on these wood-polymer composites of basswood and sugar maple. Figure 2.15 illustrates the load-defection curves that were obtained from the experimental data. The Heilman-Gulf epoxy and the tert-butylstyrene monomers were an improvement over the MMA. The tert-butylstyrenc was diluted with 50 % methanol, the wood-polymer composites contained the half of the maximum polymer loading, and the load- defection data were the same as the untreated basswood. To obtain the maximum improvement in physical properties the wood must be fully load with polymer.

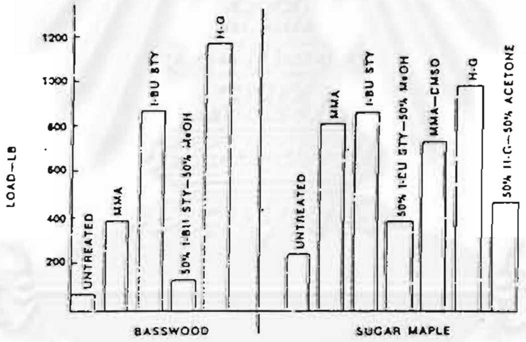


Figure 2.14 Hardness of various wood-polymer composites.

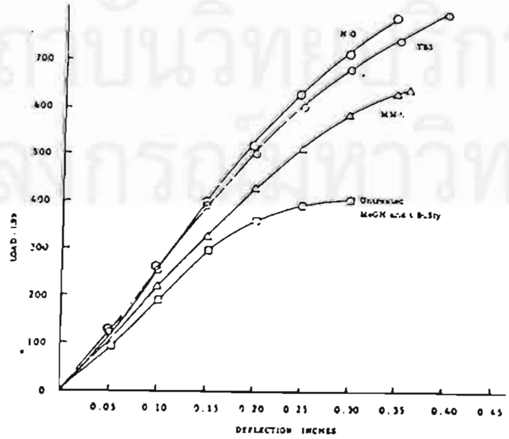


Figure2.15 Load defection curves for basswood-polymer composites.

2.9 Literature review

Wood-polymer composites (WPC), were interested by scientist since 1930. It exhibited improvement in strength, dimensional stability, and resistance to biodeterioration. The extent of improvement in property was directly related to the polymer content, which, in turn, was dependent on the type of wood, the nature of the polymer, and the processing applied. In this literature survey, various monomers, co-monomers, catalysts or initiators for preparations wood-polymer composites and properties that improved are summarized as follows:

Rozman, H.D., Kumar, R.N. and Abusamah, A. [8] studied the wood-polymer composites of rubberwood *Hevea brasiliensis*, prepared by impregnating the wood with methyl methacrylate (MMA), and the combinations of MMA and diallyl phthalate (MMA/DAP). Polymerization was carried out by catalyst heat treatment in the presence of catalyst. The result showed significant improvements in compressive and impact strengths, hardness, and dimensional stability(toward water) over that of the untreated rubberwood.

Elvy,. S.B., Dennis, G.R. and Loo- teck., N.G. [9] 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–accerelator 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.

Baki, H., Yalcin, O., and Alma, H.M. [10] 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 the wood-polymer components.

Ellis, D.W. [11] investigated the moisture sorption and swelling of wood–polymer composites. In this study maple, red Oak and southern pine specimens were saturated with acrylic and methacrylic monomers in an effort to penetrate the cell walls with monomers. The volumes of the saturated specimens were measured after each of these soak cycle. The swelling resulting from soaking the specimens with monomers was measured. The wood–polymer composites were swelled by moisture at a slower rate than that of original wood, but many wood–polymer composites eventually swelled as much as did untreated wood. Some polymers were hygroscopic, which increased the moisture content and volumetric swelling of the wood–polymer composite specimens at 90% relative humidity.

Simonsen, J. [12] attempted to overcome the deficiency of polymers which are polymerized in situ, impart desirable properties to the final composites but do not react whit the cell wall, thus their dimensional stability is therefore poor. He studied the combination of polyglycols cross-linked with dimethylal dihydroxycthylene urea (DMDHEU) in pondersa pine. He hypothesized that, if the

DMDHEU could be cross- linked with both the wood and polyglycol, the bulking effect might be rendered non leachable and dimensional stability achieved. He found that the cross–linked polyglycols showed increased swelling in some case, resulting in decreased dimensional stability. The effect was related to the specific compounds employed and their loading in the wood, resulting in failure in some case where high retention were employed.

Brebner, K.I. [13] invented the method of surface impregnation of wood articles with a plastic and to the resulting wood articles. The method includes treating dried, finished wood articles comprising the steps of degassing wood at atmospheric pressure in a diallyl o- phthalate monomer–prepolymer solution for a specified time and polymerization in the range of 200-210 degree F. in a forced air oven. The cured samples can then be buffed to obtain the desired finish.

Gayloard, N.G. [14] disclosed the preparation of polymer composites with porous cellulosic materials, such as wood. The process for forming such a composite involves in impregnation the wood with a polymerization complex of a monomer combination such as a complex of maleic anhydride and styrene. The polymerization is uncatalyzed–i.e., it is conducted without employing conventional means for inducing polymerization of monomer in wood, such as high-energy radiation or the thermal decomposition of a chemical free radical precursor. There is also disclosed a solid, stable complex of styrene and maleic anhydride.

CHAPTER 3

EXPERIMENTAL PROCEDURES

3.1 Materials

3.1.1 Para rubberwood

The small pieces of para rubberwood were obtained from wood industry. Dimension of them is 1×1×12 inches (thickness×width×length) and the surface was rough and woolly.

3.1.2 Epoxy resins and Hardener

Liquid epoxy resins and hardener were obtained from Ciba Specialty Chemicals (Thailand) Ltd.

3.1.2.1 Epoxy resins

Epoxy resin used in this study, was Araldite GY 251, a low viscosity plastified epoxy resin based on bisphenol-A, containing a non-reactive flexibilizer which may diffuse out of the film under continued thermal stress (>60 ^{0}C), in combination with polyamines, polyamidoamines or their adducts, for the production of relatively flexible solvent–free coatings, flooring screens and trowelling compounds.

3.1.2.2 Hardener

The hardener was HY2963, highly fluid, phenol-free, modified cycloaliphatic polyamine hardener. It is used in combination with liquid epoxy resins such as Araldite GY 250, GY251 and PY302-2, for the production of solvent-free coatings on surfaces subject to severe corrosion, for thank lining and floor toppings.

Properties of Araldite GY 251 and Hardener HY 2963 are shown in Table 3.1 and Table 3.2

Table 3.1 Typical data of Araldite GY 251.

Specified key data		
Aspect (visual)	clear liquid	
Colour (Gardner,ISO4630)	≤ 2	
Epoxy index (ISO 3001)	4.20 - 4.35	[eq/kg]
Epoxy equivalent (ISO 3001)	230 – 238	[g/eq]
Viscosity at 25 ^{0}C (ISO9371B)	1350 – 1600	[mPas]
Typical key data		
Density at 25 ^{0}C (ISO 1675)	1.12	[g/cm3]
Flash point (ISO 2719)	≥ 192	[^{0}C]

Table 3.2 Typical data of Hardener HY 2963

Specified key data		
Aspect (visual)	clear liquid	
Colour (Gardner, ISO4630)	≤ 2	
Amine value (DIN16945)	5.80 – 6.20	[eq/kg]
Viscousity at 25 ^{0}C (ISO9371B)	30 – 70	[mPas]
Typical key data		
H^- active equivalent weight	85	[g]
Density at 25 ^{0}C (ISO 1675)	1.12	[g/cm^3]
Flash point (ISO 2719)	≥ 192	[^{0}C]

3.1.3 Diluent

Two types of diluents were used: reactive and non-reactive type diluents.

Reactive diluent was supplied by TOA Chemicals Co., Ltd. Its trade name was Cardura E-10. It is the glycidyl ester of versatic 10, a synthetic saturated monocarboxylic acid mixture of highly branched C_{10} isomers. Cardura E-10 is used for a wide variety of paint applications, particularly those based on polyesters, acrylics and epoxy resins. Properties of Cadura E-10 are shown in Table 3.3.

Non–reactive diluent for this studied was acetone (commercial grade) supplied by Siam Chemical Industries Co. Ltd.

Table 3.3 Typical data of Cardura E-10

Property		
Appearance	clear liquid, no suspended matter	
Colour (ISO 2211)	70 max	[Pt-Co scale]
Epoxy group content (SMS 2026)	3900-4100	[mmol / kg]
(Epoxy molar mass)	244-256	[g]
Density at 20 ^{0}C (ASTM D4052)	0.985 – 0.968	[Kg / L]
Flash point (ASTM D93)	126	[^{0}C]

3.1.4 Liquid epoxy paint

Liquid epoxy paint was supplied by JBP Paint Industry. Its properties are presented in Table 3.4.

Table 3.4 Technical data of liquid epoxy paint.

Resin type	Epoxy	
Pigment type	Titanium dioxide	
Solvent type	Xylene	
Solid by weight	45 – 60	[%]
Solid by volume	38 – 45	[%]
Viscosity(25 ^{0}C)	6 – 15	[Pa.s]
Epoxy equivalent weight	450 – 500	[g/eq]

3.2 Apparatus and equipments

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

3.3 Experimental Procedures

3.3.1 Prepolymer mixtures formulation investigation

3.3.1.1 Determination of diluent type and content affecting gel time

Two types of diluent which are non-reactive diluent (acetone) and reactive diluent (Cardura E-10) in equal amount (15 phr) were mixed with epoxy resins thoroughly. Hardener (36 phr.) was added into each prepolymer mixtures. Then, the mixtures were stirred slowly to homogeneous state in polyvinyl chloride cup. The viscosity of prepolymer mixtures was measured every 10 minutes. After each measurement, the cups were put back into water bath and maintained the temperature at 30 ^{0}C. Measurement was stopped when the mixtures was too viscous to be measured or the total measuring time was more than 1 hour.

3.3.1.2 Determination of hardener content affecting gel time

Prepolymer mixtures containing 30 phr. reactive diluent were mixed with 36 phr., 27 phr., 18 phr. and 9 phr. hardener and the viscosity of them were measured every 10 minutes for 1 hour.

3.3.2 Preparation of para rubberwood–epoxy resins composites

3.3.2.1 Preparation of wood specimen

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

3.3.2.2 Determination of moisture content of specimens

Each of the prepared test specimens was weighed accurately to 0.1 g and dried in oven at 105 ^{0}C over night. Next day the dried specimens were cool down in dessicator and weighed again. Moisture content in each samples was calculated by:

$$\text{Moisture Content (\%)} = [\ X_0 - X_1 / X_1] \times 100$$

Where X_0 = Weight before drying
X_1 = Weight after drying

3.3.2.3 Preparation of impregnation prepolymer mixture

Liquid epoxy resins was weighed in metal vessel and left for a few hours. Thus, the bubbles that remained in the liquid resins were disappeared. Then, the desired amount of diluent was added and mixed homogeneously. The liquid colour was added and mixed again until the colour dispersed throughout the mixtures. After specific time, the weighed hardener was added into the mixtures and mixed slowly to allowed the hardener dispersed into in all parts of the mixtures.

3.3.2.4 Preparation of rubberwood-polymer composites

Dry wood specimens were laid in polyvinyl chloride cup. The wire net was put above the specimens and hold on by clips. This cup was put in vacuum chamber. The chamber was carefully sealed. Then, the connect valve was opened and turned on the vacuum pump. The vacuum pressure was adjusted to desired levels by turning on the adjustable screw of pump. The chamber was evacuates for specific time, then closed the connect valve followed by turn off the vacuum pump. The connect tube was put into the prepolymer mixtures, the connect valve was opened, then the prepolymer mixture was sucked into the vacuum chamber and covered all wood specimens. The connect valve was closed and allowed the specimens to soak for a specific time. Then, the connected valve between vacuum chamber was opened. The specimens cup was took out of the chamber and remove the specimens from the cup. The excess prepolymer mixtures on the surfaces of impregnated specimens was wiped off with acetone. After weighing, the impregnated specimens was kept in a glass vessel and kept in oven at 105 ^{0}C for 24 hours. Wood-polymer composites specimens that obtained were polished to get rid of polymer that clung on the surface of specimens and then kept them in the dessicator until ready for physical properties evalution.

3.3.3 Factors influencing in the preparation para rubberwood-epoxy resins composites.

3.3.3.1 Diluent types affecting properties.

The prepolymer mixtures contained 15 phr. non-reactive diluent (acetone) and reactive diluent (Cardura E-10) were prepared. Hardener 36 phr. was added to the mixtures equally. The impregnation parameters were as follows: 2 hours evacuating time, 500 mmHg evacuating pressure and 1 hour soaking time.

3.3.3.2 Hardener content affecting properties.

Hardener content at 36 phr., 27 phr. and 18 phr. was added to prepolymer mixtures, containing 30 phr. reactive diluent. For impregnation parameters, evacuating time was 2 hours, evacuating pressure was 500 mmHg., soaking time was 1 hour.

3.3.3.3 Effect of soaking time on properties

Para rubberwood-Epoxy resins composites were prepared from prepolymer mixtures that contained materials as follows: 100 phr. epoxy resins, 30 phr. reactive diluent, 27 phr. hardener, 0.5% colour. For impregnation parameters, evacuating time was 2 hours, evacuating pressure was 500 mmHg. The soaking times were vary as follows: 30, 60, 75 minutes.

3.3.3.4 Effect of evacuating time on properties.

Para rubberwood-epoxy resins composites were prepared from prepolymer mixtures that contained materials as follows: 100 phr. epoxy resins, 30 phr. reactive diluent, 27 phr. hardener, 0.5% colour. The impregnation parameters were as follows: 500 mmHg. evacuating pressure, 60 minutes soaking time, The different evacuating time as 1, 2, 3 hours were studied.

3.3.3.5 Effect of evacuating pressure on the properties

Para rubberwood-epoxy resins composites were prepared from prepolymer mixture as follows: 100 phr. epoxy resins, 30 phr. reactive diluent, 27 phr. hardener, 0.5% colour. Evacuating time was 3 hours, soaking time was 60 minutes. The different evacuating pressures as 150, 500, 650 mmHg were investigated.

3.3.4 Testing for physical properties.

Wood composites specimens were tested for the following properties:

3.3.4.1 Dimensional stability

The test items are as follows:

3.3.4.1.1 Polymer Loading (PL) [9,11]

Before impregnation, the specimens were dried in an oven at 105 °C overnight and weighed. After impregnation, the wood composites specimens were obtained. They were weighed again, then the polymer loading were calculated as follows:

$$\text{Polymer Loading} (\ \%\ ) = [\ W_t - W_0 / W_0] \times 100$$

Where W_t = Weight of treated wood or wood polymer composites

W_0 = Weight of untreated wood (oven dry)

3.3.4.1.2 Water Absorption (WA) [9,11].

Wood composites specimens were weighed to 0.1 gram accuracy. Then, they were placed vertically in the vessel. The distilled water was added untilthe upper surface of specimens was about 25 millimeters under the surface of water. The specimens were soaked for 24 hours at room temperature. After that the specimens were taken up from water and placed on the cloth, dried and weighed. Water absorption value was calculated as follows:

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

Where W_1 = Weight of specimens after water soaking

W_0 = Weight of specimens before water soaking

3.3.4.1.3 Antishrink Efficiency (ASE) [9,11].

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

$$\text{Volumetric swelling coefficient (S)} = [\ V - V_0\ ] / V_0$$

Where V = Wood volume after water soaking

V_0 = Wood volume before water soaking

$$\text{Antishrink efficiency}\ (\%) = [\ S_0 - S / S] \times 100$$

Where S_0 = Volumetric swelling coefficient for untreated sample

S = Volumetric swelling coefficient for treated sample

The dimension of specimens that tested polymer loading, water absorption, antishrink efficiency and specific gravity is shown in Figure 3.1.

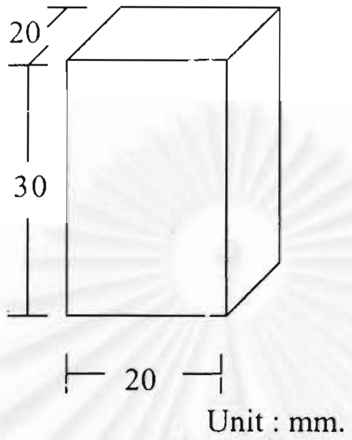


Figure 3.1 Dimensions of testing specimen.

3.3.4.1.4 Specific Gravity (sp. gr.) [ASTM D2395-93]

The weight and dimension or volumetric of wood composites specimens were measured. Specific Gravity was calculate as following formula:

$$\text{Specific Gravity} = KW_t / [1+(M/100)]Lwt$$

Where W_t = weight of specimen

M = moisture content of sample, %

L = length of specimen

W = width of specimen

K = constant

= 1 when weight is in g and volume is in cm^3

3.3.4.2 Mechanical properties

Mechanical properties are measured as follows:

3.3.4.2.2 Flexure stress and Modulus of Elasticity (MOE) [ASTM D3043-87]

Width and thickness of wood composites specimens were measured and entered values to the soft-wares of testing machine before running the test. Then flexure stress and modulus of elasticity values were obtained. The MOE corresponds to the slope of the linear portion of the stress-strain relationship from zero to the proportional limit, can be calculated from the stress – strain curve as the change in stress causing a corresponding change in strain, as follows:

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

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

ΔW = the increment in load (N)

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

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

ΔS = the increment in deflection (m)

The dimension of testing specimen is shown in Figure 3.2.

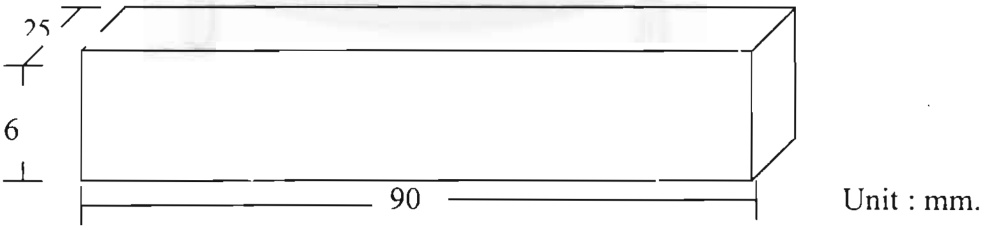


Figure 3.2 Dimension of flexure stress and MOE testing specimen.

3.3.4.2.3 Compression parallel to grain [ISO 3787-1976(E)]

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 follows:

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

where

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

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

The dimension of testing specimen is shown in Figure3.3 as follows :

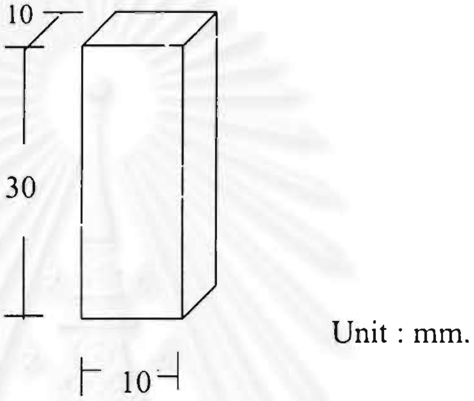


Figure 3.3 Dimension of compression parallel to grain testing specimen.

3.3.5 Microstructure of WPC Specimens.

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

The parameters of preparation of para rubberwood-epoxy resins composites, the testing properties and standard test methods are shown in Table 3-5 and 3-6.

Table 3-5 The parameters for preparation of para rubberwood-epoxy resins composites.

WPC	Diluent Types	Diluent Content phr.	Hardener Content phr.	Soaking Time min.	Evacuating Time hrs.	Evacuating Pressures mmHg.
A	Acetone	15	36	60	2	500
B	Cardura E-10	15	36	60	2	500
C	Cardura E-10	30	36	60	2	500
D	Cardura E-10	30	27	60	2	500
E	Cardura E-10	30	18	60	2	500
F	Cardura E-10	30	27	30	2	500
G	Cardura E-10	30	27	75	2	500
H	Cardura E-10	30	27	60	1	500
I	Cardura E-10	30	27	60	3	500
J	Cardura E-10	30	27	60	2	150
K	Cardura E-10	30	27	60	2	650

Table 3-6 Dimensional stability and mechanical properties of the test methods.

Dimensional stability	Test methods
Polymer loading	Reference [9],[11]
Water absorption	Reference [9],[11]
Antishrink efficiency	Reference [9],[11]

Mechanical properties	Standard test methods
Modulus of elasticity	ASTM D 3043-87
Flexure stress	ASTM D 3043-87
Compression parallel to grain	ISO 3787-1976(E)
Specific gravity	ASTM D 2395-93

CHAPTER 4

RESULT AND DISCUSSION

Para rubberwood-epoxy resins composites were prepared by impregnation para rubberwood under reduced pressure with the low viscosity prepolymer mixture. The suitable prepolymer mixtures and impregnation parameters were investigated. Dimensional stability and mechanical properties of specimens were tested and compared to obtain the optimum conditions.

4.1 Effect of diluent types on curing time

The trial experiment result of prepolymer mixture that prepared form commercially available epoxy resin and hardener showed that prepolymer mixture could not penetrate into para-rubberwood matrix under reduced pressure. This problems occurred, because the viscosity of the system was not low enough for the capillary action to uptake the mixture and the system was cured in a short time. Thus the diluent, in order to reduce the viscosity and extend curing times were mixed to the system. In this study, two types of liquid diluents, non-reactive and reactive were used. Acetone and CarduraE-10 were selected to represent the non-reactive diluent and reactive diluent, respectively.

The prepolymer mixtures were prepared by mixing 15 phr of one diluent with 100 phr liquid epoxy resin and stirred thoroughly. Then 36 phr of hardener was added in each mixture and stirred again. The viscosity of each prepolymer mixture was measured every10 minutes by Brookfield viscometer. The result was shown in Figure 4.1.

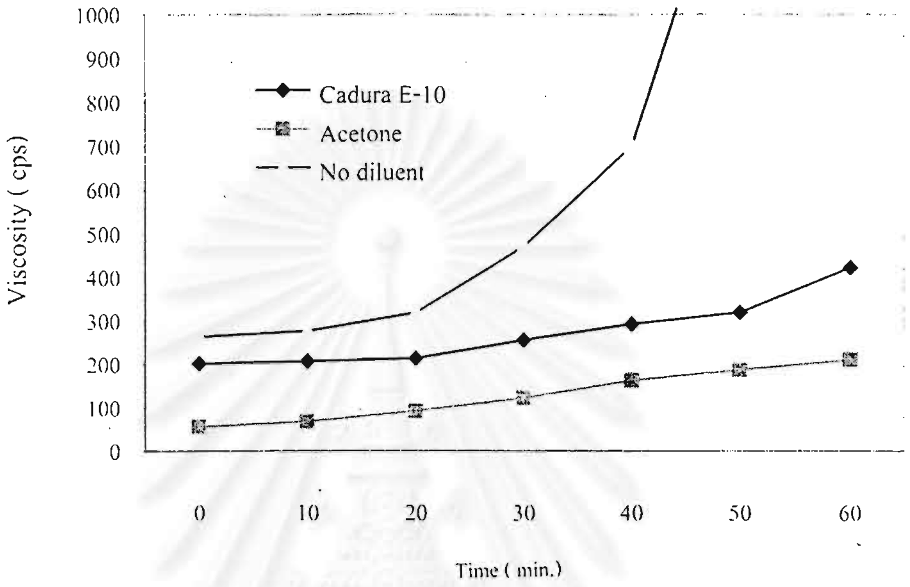
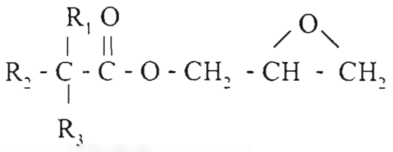


Figure 4.1 Time vs. viscosity of mixtures contained various types of diluents

The result indicated that when time increased, viscosity of prepolymer mixtures increased accordingly. At the beginning, viscosity of the undiluted system was 264 centipoise, which was the highest and increased rapidly. In comparision, viscosity of a mixture system diluted with acetone was 56 centipoise, which was lower than that diluted with Cardura E-10, which was 202 centipoise.

Acetone is a non-reactive diluent of solvent type. It was not reacted with epoxy resins, thus caused higher degree of curing system than that obtained in undiluted system. Thus, it provides viscosity reduction in epoxides.

Cardura E-10 is a reactive diluent. It is a glycidyl ester of versatic 10, a synthetic saturated monocarboxylic acid mixture of highly branched C_{10} isomers. Its structure may be represented as:



Where R_1, R_2 and R_3 are alkyl of which at least one is methyl.

Figure 4.2 Chemical structure of Cardura E-10

Since the epoxide group of Cardura E-10 is, however, also very reactive towards other chemical groups such as with alkyl or aryl amines, all the active hydrogen atoms were reacted to give hydroxyl substituted tertiary amines. Thus reactive diluent was reacted with amine groups of hardener, resulting in the reduction of cross-linking density and viscosity of prepolymer mixtures.

Both types of diluents reduced the viscosity and increased curing time of prepolymer mixtures. Therefore, the penetration of prepolymer mixtures to wood cells could happen before the viscosity of the prepolymer mixtures increased or the curing time was approached. In order to select the suitable diluent for dissolving the impregnation of prepolymer mixture and obtain better properties of impregnated samples, the effect of diluent type on properties was studied in next experiment.

4.2 Effect of diluent types on properties

In this study, the impregnated samples or wood-polymer composites were prepared from impregnated prepolymer mixtures contained 100 phr epoxy resins, 15 phr diluent, 36 phr hardener and 0.5% colour. Acetone and Cardura E-10 were dissolved in each prepolymer mixture.

Conditions of impregnation process were fixed as follows: 2 hours evacuating time, 500 mmHg evacuating pressure, 1 hour soaking time.

Experimental results of impregnated samples were shown in Table 4.1 and illustrated in Figure 4.3 and 4.4

Table 4.1 Properties of para rubberwood-epoxy resins composites prepared from different types of diluents.

Dimensional Stability	Unit	Untreated rubberwood	Diluent	
			Acetone	Cardura E-10
Polymer Loading	%	0	19.12	23.72
Water Absorption	%	37.13	20.90	7.27
ASE	%	0	33.98	40.63
Specific gravity	g/cm^3	0.63	0.71	0.84
Mechanical Properties	Unit	Untreated rubberwood	Diluent	
			Acetone	Cardura E-10
Modulus of elasticity	MPa	4553	7299	7910
Flexure Stress	MPa	97.71	110	119
Polymer loading	%	0	16.35	23.72
Compression	N/mm^2	41.50	49.27	62.48
Polymer Loading	%	0	18.93	23.74

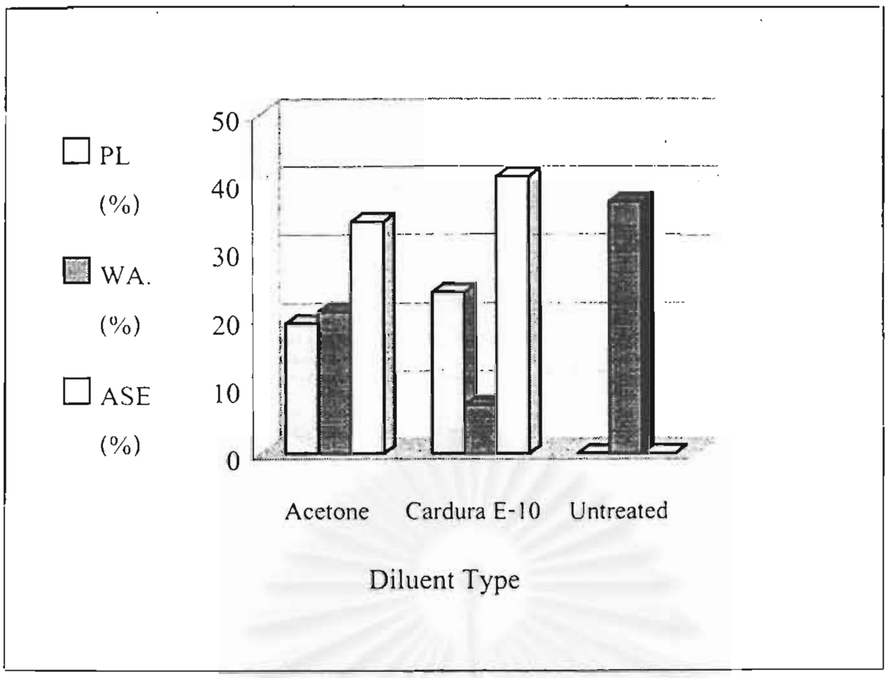


Figure 4.3 Dimensional stability of para rubberwood-epoxy resins composites prepared from various diluent types.

Polymer loading (PL) of wood–polymer composites prepared from prepolymer mixtures diluted with Cardura E-10 was higher than that diluted with acetone. It indicated that, prepolymer mixtures diluted with Cardura E-10, penetrated the wood better than the one diluted with acetone. These could be explained by the difference of boiling point between two types of diluents that effected the appearance of prepolymer mixtures. The boiling point of Cardura E-10 is 126 ^{0}C whereas acetone is -19^{0}C, so acetone volatiles at room temperature. Thus, when it volatiled in prepolymer mixtures or in the vacuum chamber, it caused some bubbles in prepolymer mixtures resulted in lost of vacuum condition. Therefore the capillary uptake penetration of wood was reduced.

Water absorption (WA) of high polymer loading samples was lower than that of low polymer loading samples and untreated samples. At the initial of impregnation, prepolymer mixtures penetrated wood cell and some epoxide group of

Cardura E-10 reacted with the hydroxyl group of cellulose, hemicellulose and lignin at the cell wall, resulting in the reduction of hydroxyl groups that attract moisture. This meant that, when the impregnated samples were soaked in water, the cell walls were not bulked to the same extent as in the untreated samples.

Antishrink efficiency (ASE) of impregnated samples that prepared from prepolymer mixtures diluted with Cardura E-10 was higher than the one that diluted with acetone and untreated samples. ASE values was calculated from the wood volume change after water soaked as mentioned in chapter 3. If water absorption of impregnated samples is low, the wood volume change is also low, thus high ASE was obtained.

The results of mechanical properties of prepolymer mixtures diluted with different types of impregnated samples is shown in Figures 4.4.

Comparison between mechanical properties such as MOE, flexure stress, compression parallel to grain of prepolymer mixtures diluted with Cardura E-10 and that diluted with acetone impregnated samples indicated that the former is superior than the latter. This performance could be explained by the following reasons.

1) The use of a solvent acetone in prepolymer mixtures, is not desirable because the volatility and highly flammability of acetone. It is evaporated before thermal polymerization. Moreover, the evaporation of the solvent deposited on the polymer would create voids in the wood-polymer composites [15]. In addition acetone can swell the wood cell wall. Therefore, the wood will undergo dimensional changes during treatment and potentially result in some distortion. For both reasons, the strength of wood-polymer composites was reduced.

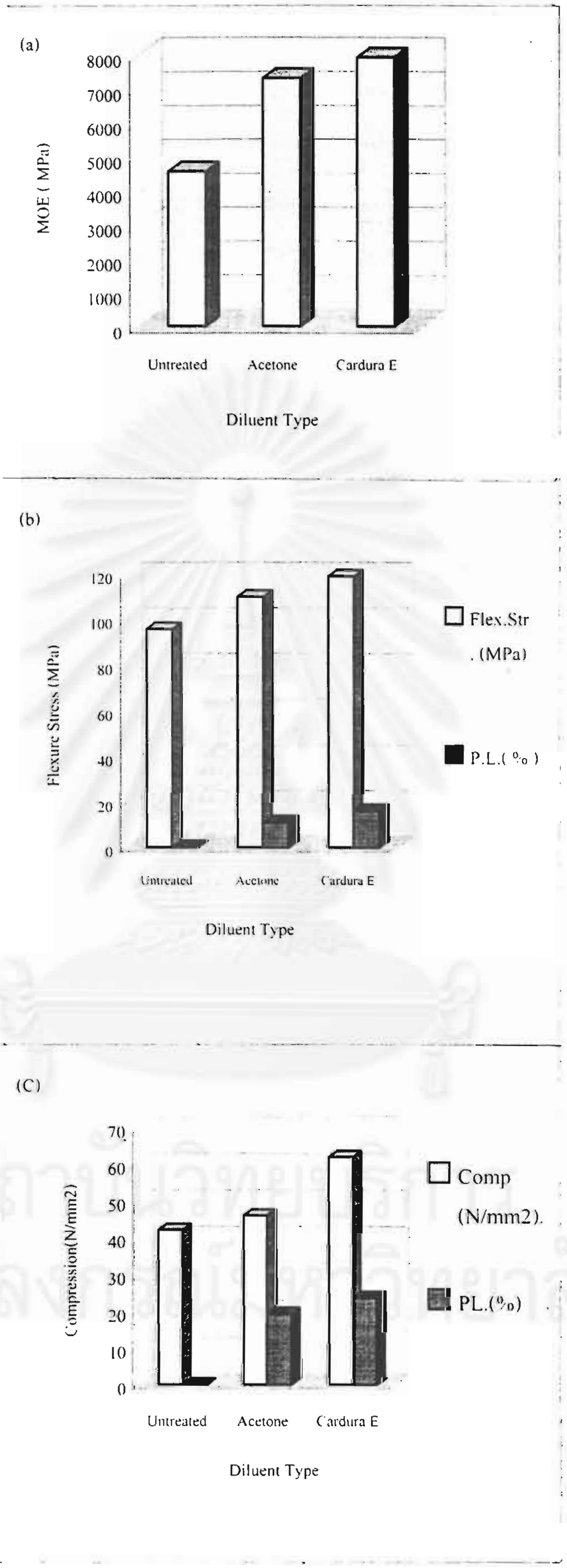


Figure 4.4 Effect of diluent types on mechanical properties.

2) Wood-polymer composites prepared from prepolymer mixtures diluted with Cardura E-10 possess wood void spaces that were retained with more polymer than the one diluted with acetone. Such wood–polymer composites may be regard as a plastic reinforced with the naturally oriented strains of wood inwhich the capillaries and interstics of wood being filled with polymer. This confirmed by polymer loading of prepolymer mixtures diluted with Cardura E-10 impregnated samples was higher than that diluted with acetone impregnated samples. The results are shown in Figure 4.3, 4.4 (b) and 4.4 (c). In addition, the epoxide groups of reactive diluent were chemically bound with the hydroxyl groups of wood and amine groups of hardener. Thus reactive diluent can alleviate some of the effects found with the non-reactive diluent.

It can be concluded that, impregnation of rubberwood with epoxy resins prepolymer mixtures dissolved in both non-reactive and reactive diluent can improve dimensional stability, mechanical properties of untreated samples on natural rubberwood. The properties of impregnated samples with reactive diluent(Cardura E-10) were better than that of non-reactive(acetone) impregnated samples. Thus the reactive diluent was selected for the viscosity reduction of the impregnated prepolymer mixtures.

4.3 Effect of hardener and diluent content on curing time

As the concentration of diluent increased, the properties of cured system such as stiffness were correspondingly reduced, so the amount of diluent was increased to 30 phr The hardener contents were decreased from 36 phr to 27 phr , 18 phr and 9 phr The viscosity of all mixed systems were measured every 10 minutes by Brookfield viscometer and the results are illustrated in Figure 4.5.

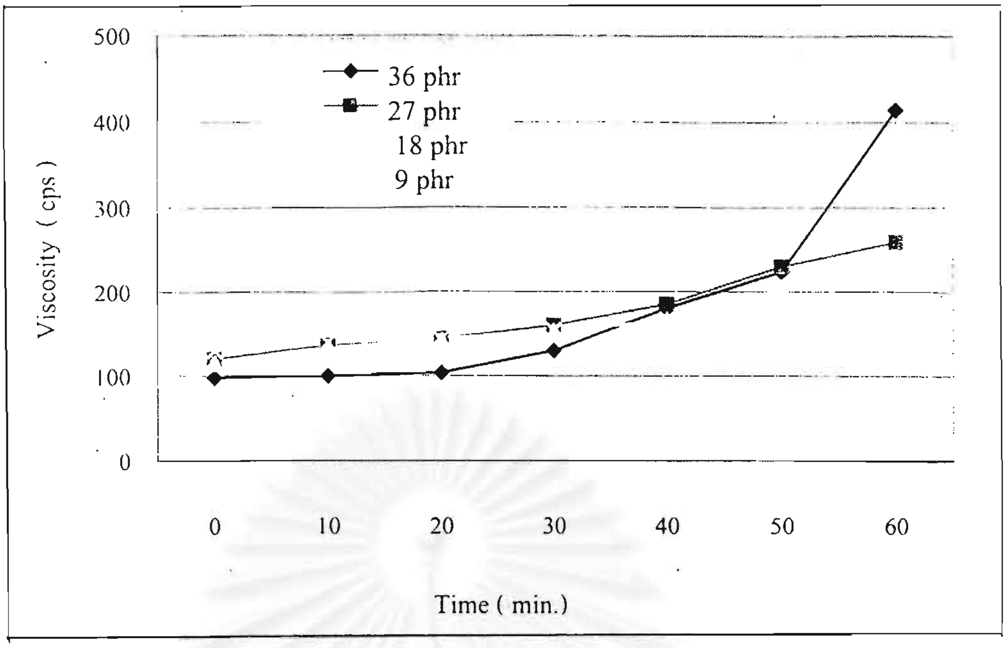


Figure 4.5 The viscosity of prepolymer mixtures containing various hardener content.

At the initial time, the viscosity of prepolymer mixtures containing 27 phr 18 phr., 9 phr hardener similar to each other, but were higher than that containing 36 phr hardener. After 30 minutes, the viscosity of them started to lower than that of 36 phr , where as the viscosity of 36 phr increased rapidly. Finally, at 60 minutes the viscosity of 36 phr was 414 cps. and was the highest comparing to 259 cps., 235 cps.,174 cps. which were the viscosity of 27 phr ,18 phr and 9 phr., respectively.

The results of this experiment showed that viscosity of prepolymer mixtures containing 30 phr of reactive diluent, and 36 phr. hardener increased faster than that contained 27 phr ,18 phr , 9 phr hardener at 30 minutes . This meant that cured time of 36 phr prepolymer mixtures was shorter. Increasing diluent content and decreasing hardener content were the ways to extended cured time. However the suitable hardener content were determined in next experiments by studied the effect of hardener contents on the properties of wood–polymer composites.

4.4 Effect of hardener content on the properties of impregnated sampled

In this experiments, hardener content were varied from 36 phr , 27 phr and 18 phr in the prepolymer mixtures containing 100 phr epoxy resins, 30 phr Cardura E-10 and 0.5 % colour. Parameters of impregnation process were as follows: 2 hours evacuating time, 60 minutes soaking time, 500 mmHg evacuating pressure. Impregnated samples gave the properties which presented in Table 4.2.

Table 4.2 Properties of Para rubberwood-Epoxy resins composites prepared from various hardener contents.

Dimensional Stability	Unit	Untreated rubberwood	Hardener Content (phr)		
			36	27	18
Polymer Loading	%	0	21.74	35.02	23.42
Water Absorption	%	37	13.16	9.90	11.84
ASE	%	0	40.61	44.83	42.23
Specific gravity	g/cm^3	0.63	0.76	0.86	0.82
Mechanical Properties	Unit	Untreated rubberwood	Hardener Content (phr)		
			36	27	18
MOE	MPa	4553	8335	9271	8279
Flexure Stress	MPa	97.71	116	154	110
Polymer Loading	%	0	17.84	22.33	19.72
Compression	N/mm^2	41.50	61	72	64
Polymer Loading	%	0	17.61	25.63	21.67

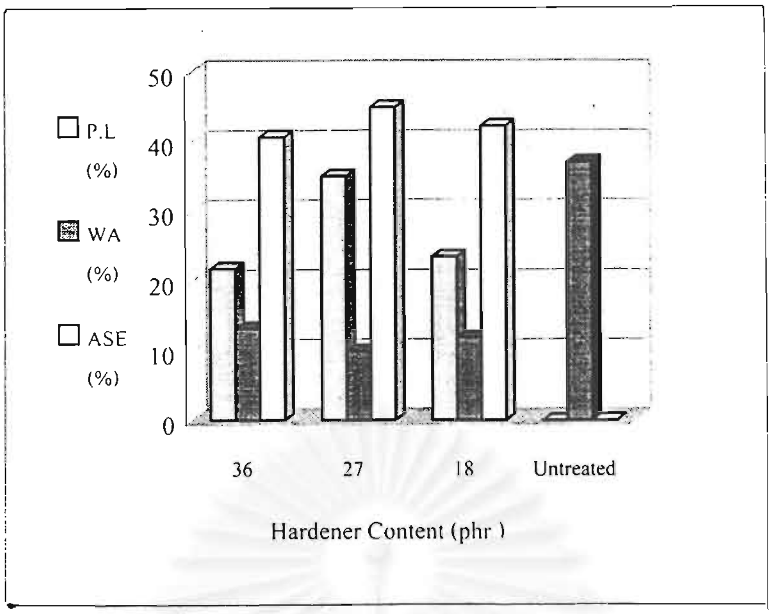


Figure 4.6 Effect of hardener content on dimensional stability.

Dimensional stability comparison of impregnated samples with various hardener contents showed that polymer loading (PL) of samples impregnated with 27 phr hardener content was the highest which consequent in lowest water absorption (WA) and highest antishrink efficiency (ASE). Samples treated with 36 phr. and 18 phr. hardener content behaved similarly. Therefore, the degree of polymer loading influenced the water absorption behavior of impregnated woods.

Although the results from 4.3 showed that, viscosity of prepolymer mixtures containing 27 phr and 18 phr hardener content were not significantly difference, hardener itself possess low viscosity, that is about 30-70 mPas. Thus the high hardener content might reduced the viscosity of prepolymer mixture. Therefore, the mixture was easy to flow though the wood grains, resulted in more polymer retained in void spaces. The effects on mechanical properties were determined and illustrated in Figure 4.7.

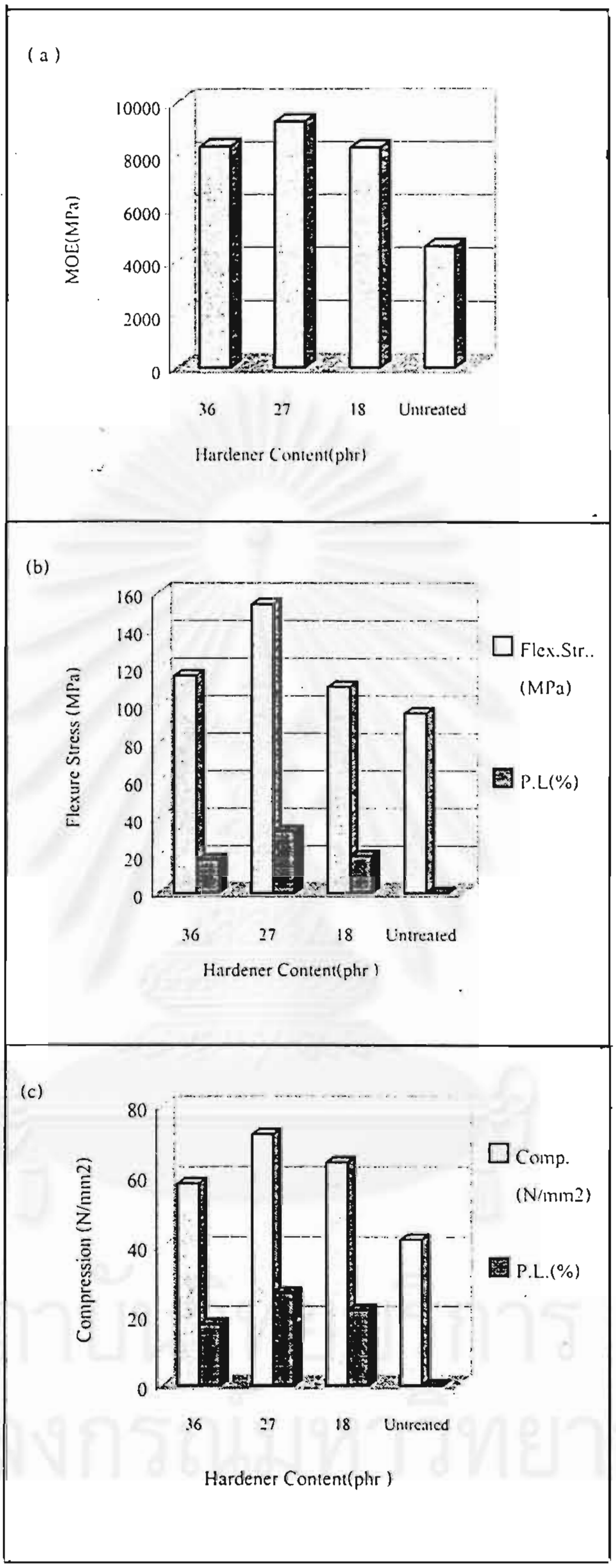


Figure 4.7 Effect of hardener content on mechanical properties.

Mechanical properties such as modulus of elasticity (MOE), flexure stress, compression parallel to grains of samples, impregnated with 27 phr hardener, showed higher values than those of the others. The same trend was observed in dimensional stability. There was no significant difference between samples treated with 36 phr and 18 phr hardener content.

This experimental results showed that samples impregnating with 27 phr hardener in prepolymer mixtures gave the superior dimensional stability and mechanical properties.

4.5 Effect of soaking time on the properties of impregnated samples

Soaking time is important in impregnation process. It is the periods used to soaked the specimens in the polymerizable mixtures. The soaking times were varied from 30, 60. 75 minutes. Another impregnating parameters were fixed as 2 hours evacuating time, 500 mmHg evacuating pressure. The prepolymer mixtures containing 100 phr epoxy resins, 30 phr Cardura E-10, 27 phr hardener, and 0.5 % color. Properties of the impregnated samples are shown in Tables 4.3 and are illustrated in Figure 4.8

Table 4.3 Properties of para rubberwood-epoxy resins composites prepared by varying soaking times.

Dimensional Stability Properties	Unit	Untreated rubberwood	Soaking Time (Minutes)		
			30	60	75
Polymer Loading	%	0	23.61	35.60	31.21
Water Absorption	%	37	14.80	14.59	10.64
ASE	%	0	31.49	31.66	35.11
Specific Gravity	g/cm^3	0.63	0.80	0.86	0.86

Table 4.3 (Continued) Properties of para rubberwood-epoxy resins composites prepared by varying soaking times

Mechanical Properties	Unit	Untreated rubberwood	Soaking Time (Minutes)		
			30	60	75
MOE	MPa	4553	8073	7147	7460
Flexure Stress	MPa	97.71	116	107	121
Polymer Loading	%	0	14.80	31.63	26.41
Compression	N/mm^2	41.50	67.81	72	69.87
Polymer Loading	%	0	23.35	30.19	24.22

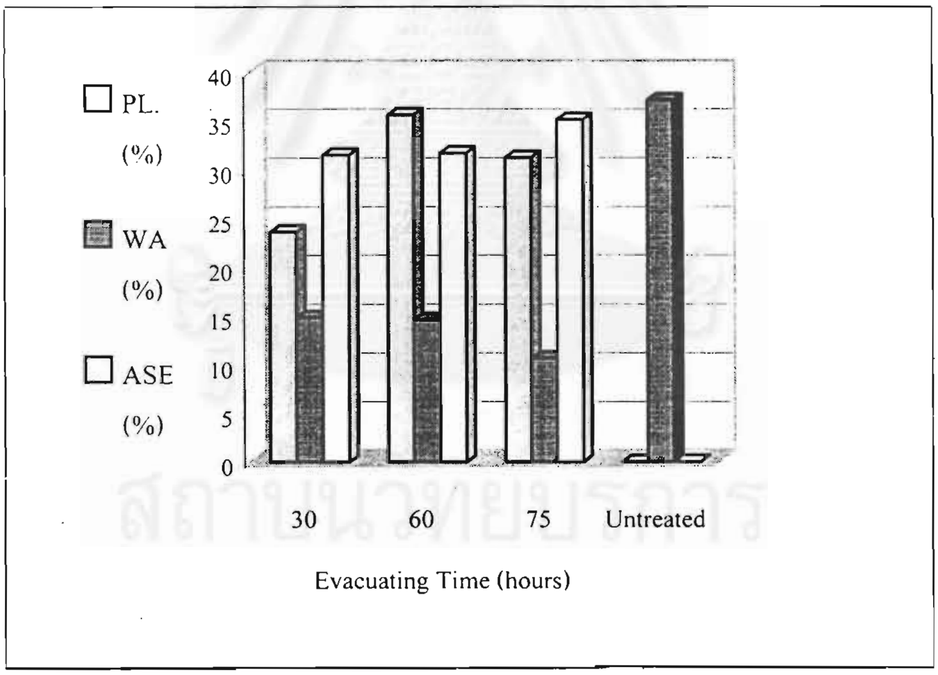


Figure 4.8 Effect of soaking times on dimensional stability.

The results of dimensional stability testing showed that, polymer loading of 30, 60, 75 minutes soaking time, were 24%, 35%, 31%. The water absorption were 15%, 16%, 11% and antishrink effciency were 31%, 32%, 35%, respectively

Although samples soaked in longer time gave higher polymer loading, they did not give lowest water absorption and highest antishrink efficiency.

The literatures [2], pointed out that when the epoxide was added to wood cell wall to such a degree, it was caused the wood structure to break apart. The details were that, after the initial reaction with a cell wall hydroxyl group, a new hydroxyl group originating from the epoxide is formed. From this new hydroxyl, a polymer begins to form. The ionic nature of the reaction and the availability of alkoxyl ions in the wood components probably produced chain transfer, thereby yielding a short chain length. The formation of polymer in the cell wall may be the cause of cell wall rupture at high polymer loading.

When the polymer loading was more than about 30%, the volume of the treated wood was greater than that of green wood. This was the level, where the ASE started to drop. This meant that the polymer loading was now so high. They have broken the cell wall and allowed the wood to superswell above the green wood volume. Therefore, water absorption of high polymer loading samples was high and ASE was low.

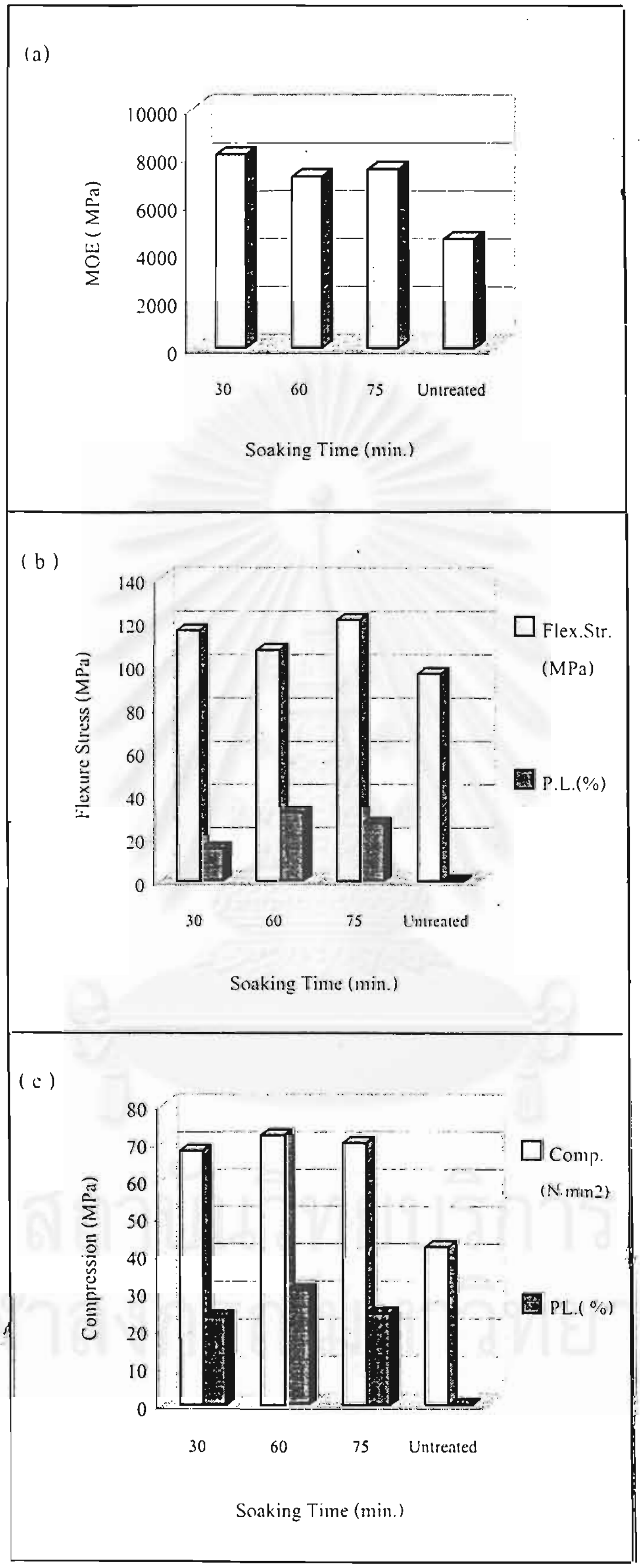


Figure 4.9 Effect of soaking times on mechanical properties

MOE testing samples soaked at 30, 60, 75 minutes were 8073, 7147, 7460 MPa in MOE. Flexure stress were 116, 107, 121 MPa, polymer loading were 14.8, 31.63, 26.41%, respectively. This results, it shows that, longer soaking time gave higher polymer loading which resulted in lower MOE and flexure stress. The higher polymer loading caused the structure of wood to break apart as explained above. Thus the samples were bent easier when bent when tested.

Compression parallel to grain testing samples, that soaked at 30, 60, 75 minutes gave 67, 72, 69 N/mm^2 compression value. The polymer loading were 22, 26, 23%, respectively. The higher polymer loading that obtained from longer soaking time samples gave higher compression parallel to grain values. This was because wood is contained a bundle of straws bound together, and a compression parallel to grains could be though of a force trying to compress the straws from end to end. If the polymer contained in wood cells were high, it was increased the stiffness of the straws and resulted in high compression values.

Soaking times, 60 minutes is the periods that treated samples showed the highest polymer loading. This effected the properties of impregnated samples. Thus, 60 minutes soaking time was selected to studied for other impregnation parameters in next experiment. .

4.6 Effect of evacuating times on the properties of impregnated samples.

Evacuating time was the times, used to evacuate air from the void spaces of wood cells. It was assumed that, the longer evacuating times, the more void spaces, that free of air obtained. So it was benefit for prepolymer mixtures to penetrated the wood cells. In this studied the evacuating times were invested to 1,2,3 hours. Results of this experiments are shown in Table 4.4 and are illustrated in Figure 4.10, 4.11 .

Table 4.4 Properties of Para rubberwood-epoxy resins composites prepared from various evacuating times.

Dimensional Stability	Unit	Untreated rubberwood	Evacuating time (hours)		
			1	2	3
Polymer Loading	%	0	30.89	35.02	34.39
Water Absorption	%	37	11.64	9.90	10.49
ASE	%	0	34.40	44.83	39.19
Specific gravity	g/cm^3	0.63	0.84	0.86	0.83
Mechanical Properties	Unit	Untreated rubberwood	Evacuating times (hours)		
			1	2	3
MOE	MPa	4553	5462	9271	7069
Flexure Stress	MPa	97	112	154	140
Polymer Loading	%	0	27.44	21.33	20.59
Compression	N/mm^2	42	69	72	74
Polymer Loading	%	0	32.39	25.63	29.74

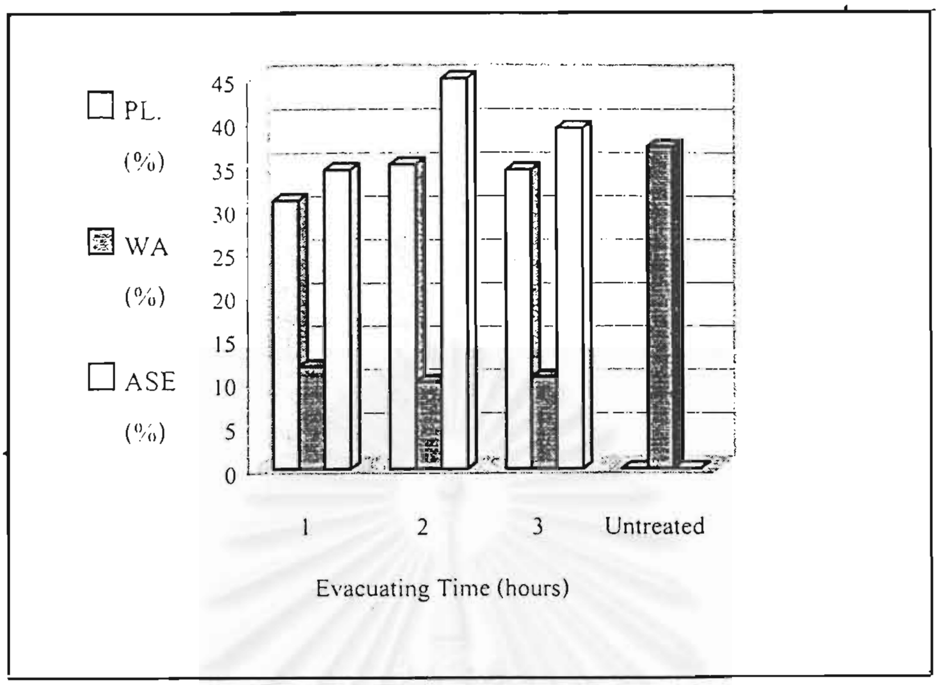


Figure 4.10 Effect of evacuating time on dimensional stability.

The results of dimensional stability test showed that, 2 and 3 hours evacuating time samples, gave higher polymer loading than 1 hour evacuating time. The long evacuating time, gave the ability to evacuat air from the wood cells. It allowed the opportunity for prepolymer mixture to penetrate into empty wood cells and retained in there. The more polymer filled in the wood cells, the lower water absorption was. Since the water was not absorbed into the wood cell, thus, dimension of wood would not change. The ASE of wood-polymer composites were higher than untreated woods.

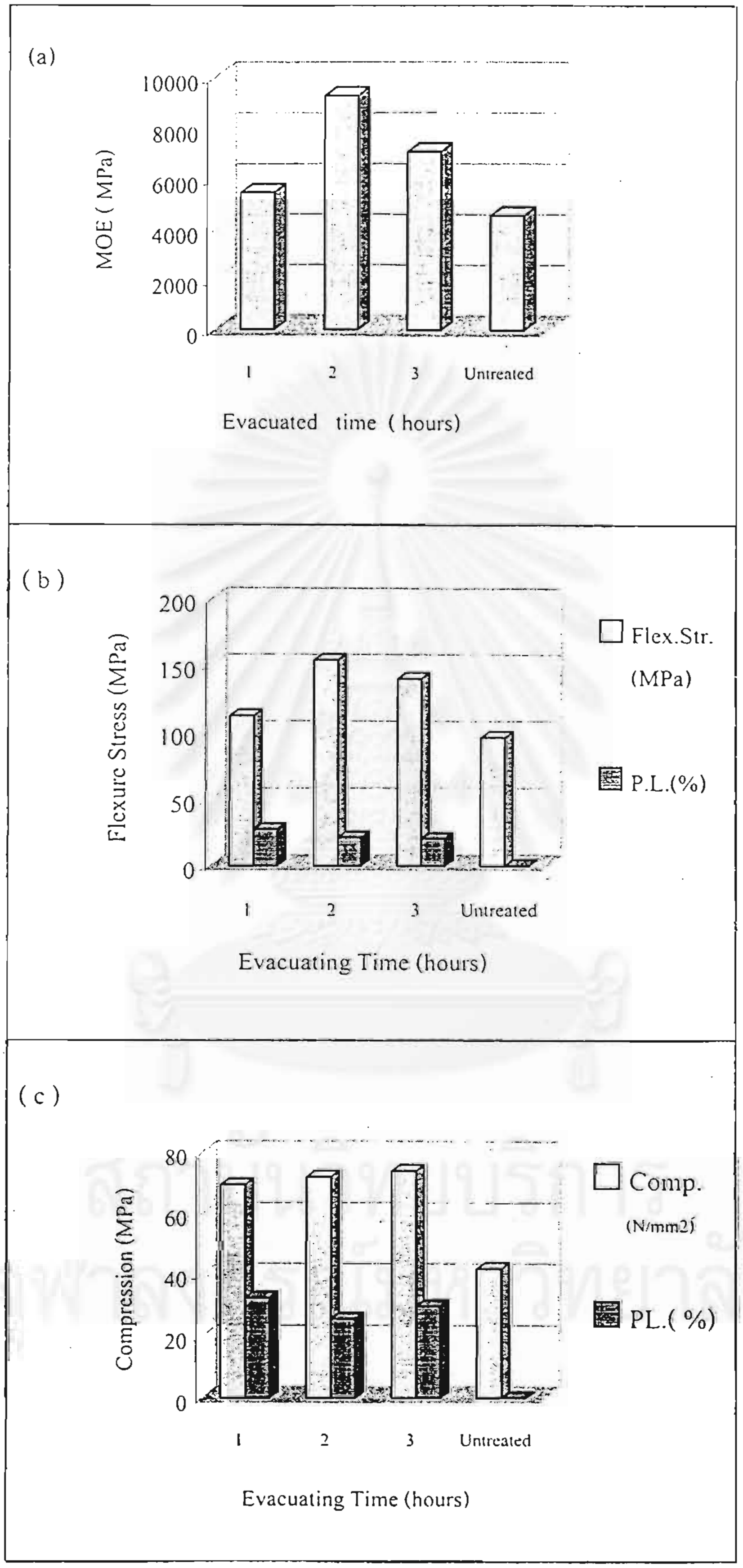


Figure 4.11 Effect of evacuating times on mechanical properties .

Mechanical properties of various evacuating time samples are shown in Figure 4.11. Both 2 and 3 hours evacuating samples, showed significant improvement in MOE (about 55-100 %), compared to untreated samples. However, there was no significant difference between specimens obtained from1 hour evacuating time and untreated samples. Flexure stress of samples, evacuated 2 and 3 hours performed the same trend of MOE results. Impregnated samples, at various evacuating time, showed significant improvements in compressive strength and specific gravity values were higher than untreated samples. Generally, all treated samples, showed improvement in mechanical properties with lower polymer loading compared to untreated samples.

From all of results, it was found that at the evacuating time of 2 hours the best dimensional stability and mechanical properties of treated samples was obtained. Therefore, the evacuating time of 2 hours was used to study the effect of evacuating pressure on properties of impregnated samples.

4.7 Effect of evacuating pressure on the properties of impregnated samples

In this part of work, 60 minutes soaking time and 2 hours evacuating time were used. The effect of evacuating pressure on the properties of wood-polymer composites is shown in Table 4.5. From Figure 4.12, the highest polymer loading at 650 mmHg treated samples was about 51%. This highest degree of polymer loading caused low water absorption of impregnated samples. But the ASE was dropped significanly compared with 500 mmHg impregnated samples.

Table 4.5 Properties of Para rubberwood-epoxy resins composites prepared from various evacuating pressures.

Dimensional Stability	Unit	Untreated rubberwood	Evacuating pressure (mmHg)		
			650	500	150
Polymer Loading	%	0	51.07	35.02	10.25
Water Absorption	%	37	10.88	9.90	16.84
ASE	%	0	29.13	44.83	25.49
Specific gravity	g/cm^3	0.63	0.95	0.86	0.74
Mechanical Properties	Unit	Untreated rubberwood	Evacuating pressure (mmHg)		
			650	500	150
MOE	MPa	4553	4384	9271	3612
Flexure Stress	MPa	97	119	154	87
Polymer Loading	%	0	32.40	21.33	13.44
Compression	N/mm^2	42	63.28	72	52.63
Polymer Loading	%	0	40.16	25.63	12.84

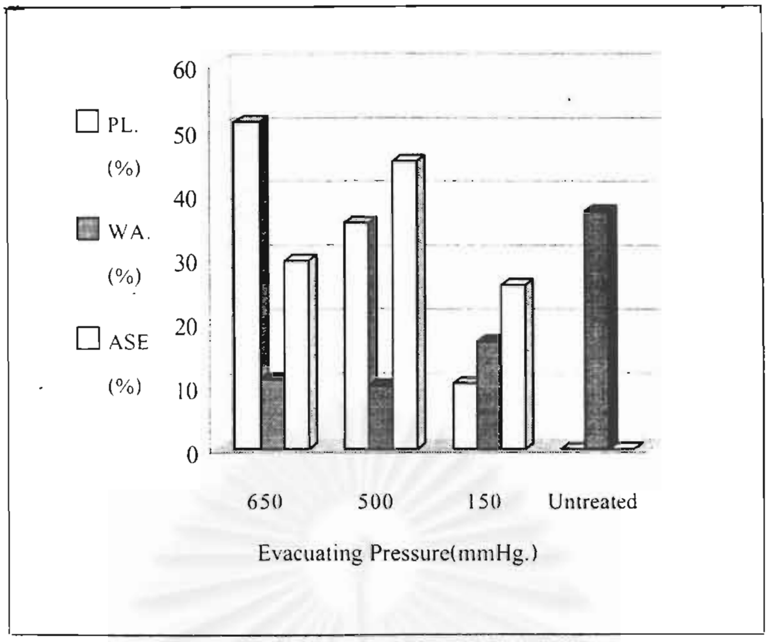


Figure 4.12 Effect of evacuating pressure on dimensional stability of impregnated samples.

The effect of evacuating pressure on mechanical properties is shown in Figure 4.13. Samples impregnated at 500 mmHg. of evacuating pressure, showed highest improvement in MOE, flexure stress and compression parallel to grains. These performances were the best compared to other WPC samples and untreated samples. Specific gravity of untreated samples at 150, 500, 650 mmHg. evacuating samples were 0.63, 0.74, 0.86, 0.95 g/cm^3 respectively. It showed that, more polymer loading samples gave higher value of specific gravity.

It was found that for the dimensional stability test samples impregnated at 650 mmHg gave the highest polymer loading but low ASE, compared to 500 mmHg treated samples. In contrast, the mechanical properties test samples impregnatd at 500 mmHg showed the best quality. Therefore, 500 mmHg was selected as evacuating pressure.

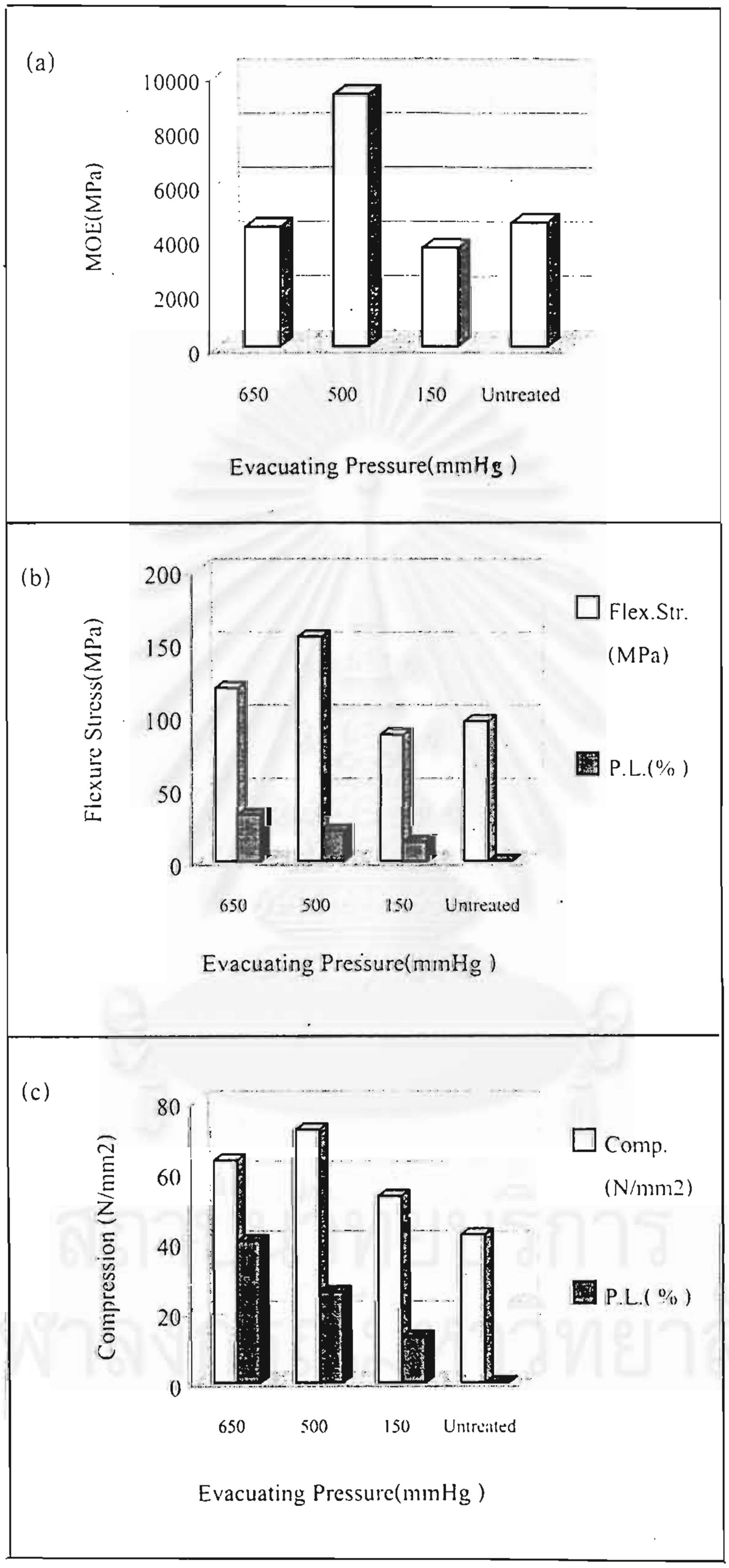


Figure 4.13 Effect of evacuating pressure on mechanical properties.

4.8 Scanning Electron Microscopy(SEM) of WPC

The microstructure of wood-polymer composites (WPC) were examined by scanning electron microscopy (SEM) of transverse sections of the specimens. The microstructures of untreated rubberwood cells are shown in Figure 4.14 and 4.15. The microstructures of impregnated wood cells are shown in Figure 4.16 and 4.17.

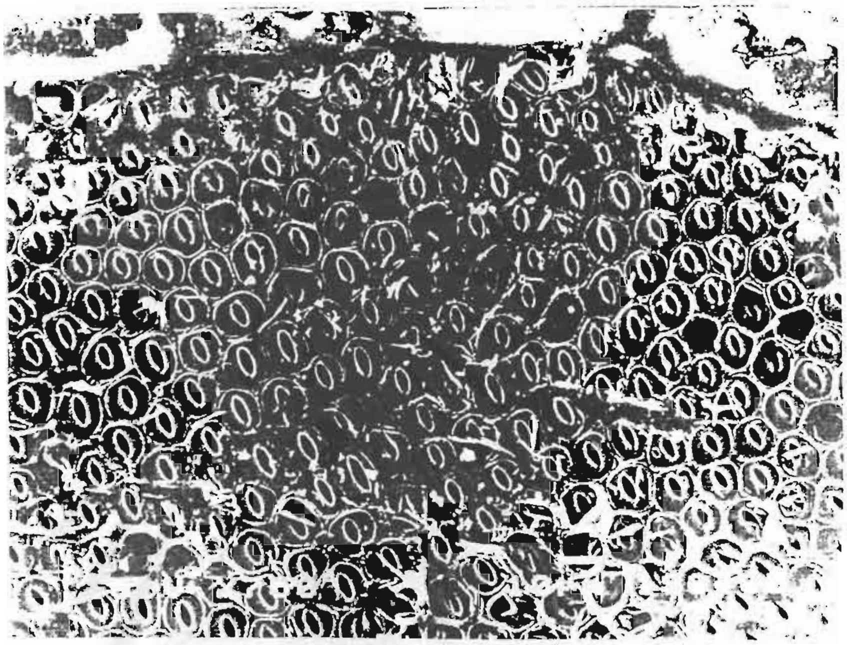


Figure 4.14 Scanning electron micrograph of transverse section of empty wood cells(750X).

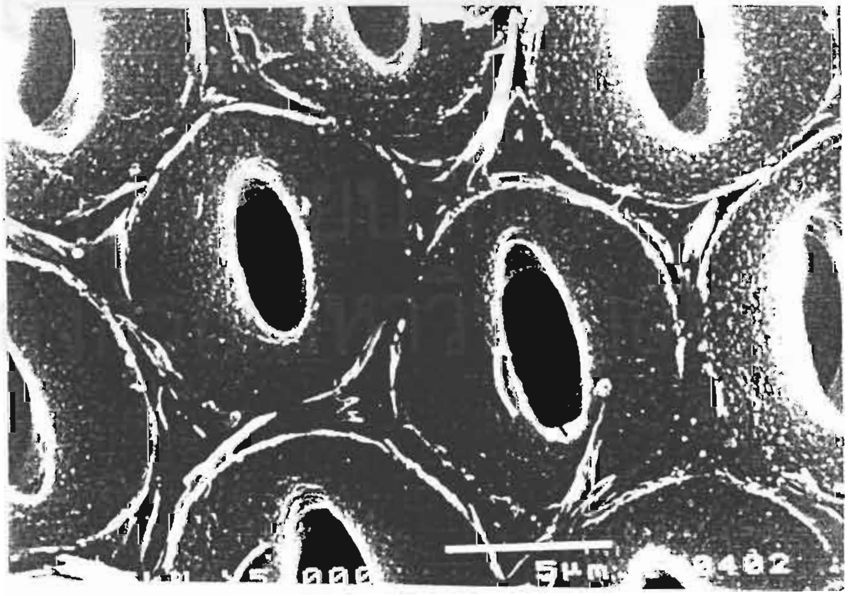


Figure 4.15 Scanning electron micrograph of transverse section of empty wood cells(5,000X).

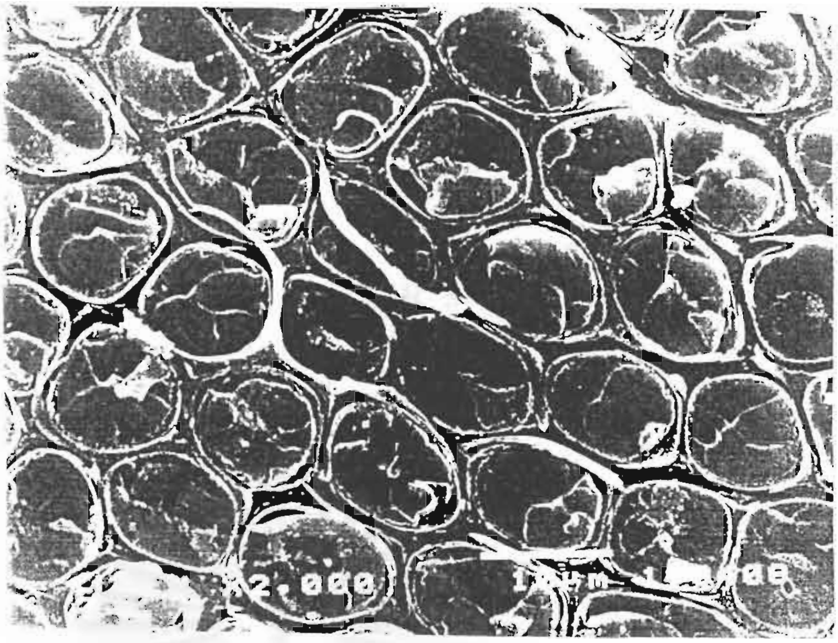


Figure 4.16 Scanning electron micrograph of transverse section of polymer filled cells (2,000X).

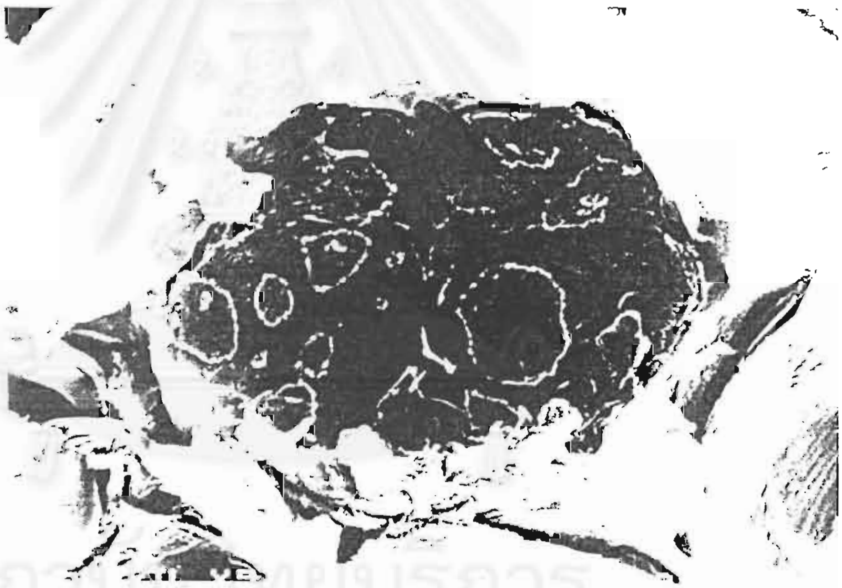


Figure 4.17 Scanning electron micrograph of transverse section of polymer filled cells (5,000X).

The microstructure of untreated rubberwood cells showed the empty void spaces. In impregnation process, the air was evacuated from this void spaces. The empty wood cells were fully filled with polymer, there was important consequence on improvement in dimensional stability and mechanical properties of natural wood.

CHAPTER 5

CONCLUSION

Dimensional stability and mechanical properties of para rubberwood-epoxy resins composites, prepared from impregnation under reduced pressure process, were depended on raw material content in prepolymer mixtures and preparation parameters. The optimum values were as follows:

reactive diluent content	30	phr
hardener content	27	phr
soaking time	1	hour
evacuating time	2	hours
evacuating pressure	500	mmHg

Para rubber wood-epoxy resins composites obtained under these conditions, gave moderately polymer loading and water absorption, high antishrink efficiency (ASE) in dimensional stability. For mechanical properties, it showed high modulus of elasticity (MOE), compression parallel to grains and flexure stress but moderately specific gravity.

The water absorption of para rubberwood –epoxy resins composites was significant lower than natural rubberwood but modulus of elasticity, flexure stress, compression parallel to grains were higher than untreated natural rubberwood. Consequently, the mechanical properties of natural rubberwood were improved.

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APPENDIXS

APPENDIX A

DATA OF TESTING PROPERTIES

Table A-1 Testing properties of natural rubberwood

Dimensional Stability			Mechanical Properties			
Sample/piece unit	Water abrorption %	Swelling Coefficient S	Specific gravity g/cm3	Modulus of elasticity MPa	Flexure stress MPa	Compression N/mm2
1/1	35.46	5.37	0.63	4177	-	44.53
1/2	40.69	5.04	0.64	-	97.17	-
1/3	39.82	7.91	0.63	4965	102.5	38.02
1/4	39.50	-	0.64	4437	98.28	42.59
1/5	-	9.98	0.64	5322	99.56	43.85
averg.	38.87	7.07	0.63	4725	99.38	42.24
2/1	41.32	-	0.65	-	98.60	-
2/2	31.00	10.76	0.62	4288	90.55	44.31
3/3	-	-	0.62	3983	-	40.27
4/4	33.85	11.73	0.62	3702	90.35	37.34
5/5	35.29	12.97	0.62	4171	88.66	41.16
averg.	35.37	11.82	0.63	4381	92.04	40.77
averg.	37.12	9.45	0.63	4553	95.71	41.50
SD.	2.48	3.36	0.00	243	5.19	1.04

Table A-2 Testing properties of Para rubberwood-Epoxy resins Composites A

Dimensional Stability					Mechanical Properties				
Sample/piece unit	Polymer Loading %	Water abrorption %	ASE %	Specific gravity g/cm3	Modulus of elasticity MPa	Flexure stress MPa	Polymer Loading %	Compression N/mm2	Polymer Loading %
1/1	13.43	20.18	35.89	0.66	7240	107	10.11	40.75	17.06
1/2	16.12	20.35	33.72	0.71	7185	109	10.12	43.47	16.98
1/3	18.04	-	32.58	0.73	7245	108	10.15	49.65	18.87
1/4	19.46	22.64	28.35	0.69	7357	110	10.16	47.30	19.02
1/5	-	16.57	36.49	0.76	7288	112	10.17	45.69	18.88
averg.	16.76	19.94	33.41	0.71	7263	109	10.14	45.37	18.16
MC.(%)	7.79	7.79	7.79	7.79	8.15	8.15	-	8.18	-
2/1	13.49	22.96	36.45	0.67	7185	109	11.77	45.42	19.87
2/2	14.25	22.88	30.14	0.68	7255	106	11.87	44.45	20.02
3/3	17.13	19.77	37.26	0.71	7240	111	11.91	45.26	20.45
4/4	-	20.48	32.76	0.74	7456	117	11.92	46.07	20.55
5/5	18.90	23.21	36.15	0.76	7537	115	11.67	47.44	20.67
averg.	15.94	21.86	34.55	0.71	7335	112	11.83	45.73	20.31
MC.(%)	8.04	8.04	8.04	8.04	8.29	8.29	-	8.29	-
averg.	16.35	20.90	33.98	0.71	7299	110	10.99	45.55	19.24
SD.	0.58	1.36	0.81	0.00	50.63	1.70	1.19	0.25	1.52
averg. MC.(%)	7.92	7.92	7.92	7.92	8,22	8.22	-	8.24	-

Table A-3 Testing properties of Para rubberwood-Epoxy resins Composites B

Dimensional Stability					Mechanical Propertics				
Sample/piece unit	Polymer Loading %	Water abrorption %	ASE %	Specific gravity g/cm3	Modulus of elasticity MPa	Flexure stress MPa	Polymer Loading %	Compression N/mm2	Polymer Loading %
1/1	26.08	7.14	35.69	0.82	7280	119	17.2	52.53	22.90
1/2	25.04	7.08	37.50	0.81	8571	120	17.3	66.33	23.05
1/3	21.48	9.56	38.14	0.81	7926	123	17.25	55.21	23.35
1/4	24.48	8.87	42.04	0.83	7514	121	17.12	67.56	23.15
1/5	23.29	6.08	38.34	0.84	7856	110	16.95	-	23.25
averg.	24.07	7.75	38.34	0.82	7829	119	17.16	60.41	23.14
MC.(%)	9.22	9.22	9.22	9.22	7.92	7.92	-	7.47	-
2/1	23.22	7.29	-	0.82	8610	121	14.40	60.56	24.05
2/2	23.74	8.15	41.65	0.82	7717	121	15.50	64.50	24.10
3/3	26.71	6.43	48.85	0.85	7586	119	15.65	62.75	24.08
4/4	20.81	5.9	42.2	0.86	7687	118	14.75	64.60	24.20
5/5	22.37	6.21	38.93	0.92	8354	117	16.02	63.56	24.30
averg.	23.37	6.80	42.91	0.85	7991	119	15.26	63.19	24.15
MC.(%)	7.04	7.04	7.04	7.04	8.04	8.04	-	8.24	-
averg.	23.72	7.27	40.63	0.84	7910	119	16.21	61.80	23.64
SD.	0.50	0.67	3.23	0.02	114	0.40	1.34	1.97	0.71
averg. MC.(%)	8.13	8.13	8.13	8.13	7.98	7.98	-	7.86	-

Table A-4 Testing properties of Para rubberwood-Epoxy resins Composites C

Dimensional Stability					Mechanical Properties				
Sample/piece unit	Polymer Loading %	Water abrorption %	ASE %	Specific gravity g/cm3	Modulus of elasticity MPa	Flexure stress MPa	Polymer Loading %	Compression N/mm2	Polymer Loading %
1/1	21.95	15.13	39.21	0.67	8150	126	16.78	60.87	19.55
1/2	26.40	13.49	-	0.80	8658	107	17.25	-	19.12
1/3	21.48	12.25	45.16	0.95	8443	105	17.30	-	18.25
1/4	-	14.50	46.11	0.77	8660	128	17.45	57.49	16.70
1/5	-	15.10	42.84	0.67	8215	118	17.50	51.74	16.80
averg.	23.28	14.09	43.33	0.77	8425	117	17.26	56.70	18.08
MC.(%)	7.15	7.15	7.15	7.15	7.04	7.04	-	7.76	-
2/1	20.09	15.44	-	0.73	8750	106	18.90	59.24	17.30
2/2	21.65	11.83	32.90	0.69	7956	121	17.90	58.50	16.70
3/3	19.75	10.30	37.39	0.77	7856	119	18.80	57.60	17.40
4/4	19.64	10.14	39.13	0.76	8102	118	17.80	59.10	16.80
5/5	19.92	13.40	42.14	0.77	8556	114	18.70	58.20	17.50
averg.	20.21	12.22	37.89	0.74	8244	116	18.42	58.53	17.14
MC.(%)	7.25	7.25	7.25	7.25	7.54	7.54	-	7.21	-
averg.	21.74	13.16	40.61	0.76	8335	116	17.84	57.61	17.61
SD.	2.17	1.32	3.85	0.02	128	0.85	0.82	1.29	0.67
averg. MC.(%)	7.20	7.20	7.20	7.20	7.29	7.29	-	7.49	-

Table A-5 Testing properties of Para rubberwood-Epoxy resins Composites D

Dimensional Stability				Mechanical Properties					
Sample/piece unit	Polymer Loading %	Water abrorption %	ASE %	Specific gravity g/cm3	Modulus of elasticity MPa	Flexure stress MPa	Polymer Loading %	Compression N/mm2	Polymer Loading %
1/1	33.97	10.15	43.67	0.88	9318	153	23.50	70.71	24.20
1/2	35.50	10.20	42.88	0.88	8690	156	24.10	73.85	25.95
1/3	30.35	9.89	43.50	0.90	9806	159	23.75	74.37	25.90
1/4	33.24	10.10	44.10	0.83	8565	158	23.80	73.46	25.75
1/5	34.66	10.25	42.95	0.85	9256	154	24.15	74.45	24.35
averg.	33.54	10.12	43.42	0.87	9127	156	23.86	73.37	25.23
MC.(%)	7.14	7.14	7.14	6.77	6.77	6.77	-	5.98	-
2/1	36.50	9.60	46.71	0.84	9456	150	20.45	70.30	26.10
2/2	35.80	9.70	45.60	0.82	9566	153	21.35	69.10	25.80
3/3	36.64	9.55	46.20	0.85	9377	152	21.65	71.20	26.20
4/4	37.66	9.50	45.60	0.82	9420	151	20.35	72.50	25.75
5/5	35.90	10.10	47.10	0.89	9254	151	20.15	69.70	26.30
averg.	36.50	9.69	46.24	0.84	9415	151	20.79	70.56	26.03
MC.(%)	6.99	6.99	6.99	6.89	6.89	6.89	-	5.84	-
averg.	35.02	9.90	44.83	0.86	9271	154	22.33	71.96	25.63
SD.	2.09	0.30	2.00	0.02	203	3.21	2.17	1.99	0.57
averg. MC.(%)	7.07	7.07	7.07	6.83	6.83	6.83	-	5.91	-

Table A-6 Testing properties of Para rubberwood-Epoxy resins Composites E

Dimensional Stability					Mechanical Properties				
Sample/piece unit	Polymer Loading %	Water abrorption %	ASE %	Specific gravity g/cm3	Modulus of elasticity MPa	Flexure stress MPa	Polymer Loading %	Compression N/mm2	Polymer Loading %
1/1	25.09	12.15	42.97	0.83	7928	107	20.05	66.95	19.80
1/2	22.69	12.27	42.88	0.84	8177	114	19.95	65.21	20.25
1/3	20.44	12.32	43.50	0.81	8076	108	20.10	64.75	20.10
1/4	29.31	10.19	42.91	0.88	8190	110	19.90	63.85	19.75
1/5	25.00	10.75	42.84	0.77	8278	105	20.50	66.80	20.50
averg.	24.51	11.54	43.02	0.83	8130	109	20.10	65.51	20.08
MC.(%)	7.56	7.56	7.56	7.56	8.25	8.25	-	7.38	-
2/1	23.75	12.35	43.36	0.84	8376	107	19.20	63.20	25.30
2/2	22.80	11.83	41.08	0.83	8477	114	19.25	61.35	24.25
3/3	22.60	12.98	39.85	0.83	8514	118	19.10	62.40	23.20
4/4	21.67	13.25	42.57	0.83	8120	105	18.95	64.25	22.20
5/5	20.85	10.28	40.36	0.75	8655	109	20.15	63.45	21.35
averg.	22.33	12.14	41.44	0.82	8428	111	19.33	62.93	23.26
MC.(%)	7.65	7.65	7.65	7.65	7.92	7.92	-	6.93	-
averg.	23.42	11.84	42.23	0.82	8279	110	19.72	64.22	21.67
SD.	1.54	0.43	1.11	0.01	211	1.27	0.54	1.83	2.25
averg. MC.(%)	7.61	7.61	7.61	7.61	8.09	8.09	-	7.16	-

Table A-7 Testing properties of Para rubberwood-Epoxy resins Composites F

Dimensional Stability					Mechanical Properties				
Sample/piece unit	Polymer Loading %	Water abrorption %	ASE %	Specific gravity g/cm3	Modulus of elasticity MPa	Flexure stress MPa	Polymer Loading %	Compression N/mm2	Polymer Loading %
1/1	34.42	15.87	26.21	0.79	7987	108	17.40	66.03	24.26
1/2	36.26	16.90	23.89	0.79	8020	111	16.95	65.08	23.50
1/3	-	13.02	28.43	0.84	8165	114	15.80	-	23.10
1/4	34.39	15.43	27.47	0.75	7895	116	14.35	66.84	23.55
1/5	33.33	15.67	-	0.75	8278	118	20.50	69.04	24.10
averg.	34.60	15.38	26.50	0.78	8069	113	17.00	66.75	23.72
MC.(%)	7.95	7.95	7.95	7.95	7.05	7.05	-	8.19	-
2/1	34.20	13.32	27.80	0.77	7655	119	19.20	68.71	22.40
2/2	35.10	14.92	26.50	0.79	7539	114	19.25	67.85	21.35
3/3	33.25	11.13	28.30	0.88	8095	123	19.10	69.10	22.10
4/4	34.30	13.35	27.70	0.77	7398	115	18.95	70.25	21.10
5/5	35.20	12.55	28.10	0.88	8125	120	20.15	68.50	23.25
averg.	34.41	13.05	27.68	0.82	7762	118	19.33	68.88	22.04
MC.(%)	7.52	7.52	7.52	7.52	7.42	7.42	-	9.10	-
averg.	34.51	14.22	27.09	0.80	7916	116	18.17	67.81	22.88
SD.	0.13	1.64	0.83	0.02	217	3.39	1.65	1.51	1.19
averg. MC.(%)	7.74	7.74	7.74	7.74	7.24	7.24	-	8.65	-

Table A-8 Testing properties of Para rubberwood-Epoxy resins Composites G

Dimensional Stability					Mechanical Properties				
Sample/piece unit	Polymer Loading %	Water abrorption %	ASE %	Specific gravity g/cm3	Modulus of elasticity MPa	Flexure stress MPa	Polymer Loading %	Compression N/mm2	Polymer Loading %
1/1	29.49	9.98	38.61	0.86	7289	123	26.50	65.77	24.26
1/2	32.33	8.43	34.99	0.88	7595	120	25.65	69.88	23.50
1/3	26.18	9.58	35.65	0.84	8055	127	26.70	70.12	23.10
1/4	24.37	11.82	36.77	0.82	7786	-	27.10	68.95	23.65
1/5	33.33	9.49	37.50	0.88	7985	116	24.50	69.10	24.10
averg.	29.14	9.86	36.70	0.86	7742	122	26.09	68.76	23.72
MC.(%)	7.12	7.12	7.12	7.12	6.39	6.39	-	5.19	-
2/1	32.28	10.62	37.50	0.87	7256	120	26.05	69.65	22.40
2/2	34.18	10.00	38.25	0.88	7421	115	25.10	70.56	21.35
3/3	29.54	11.24	39.20	0.84	7095	125	24.90	71.25	22.10
4/4	28.42	12.68	35.75	0.85	7185	118	20.85	70.85	21.10
5/5	35.65	10.08	40.10	0.88	7385	116	22.95	72.55	23.25
averg.	32.01	10.92	38.16	0.86	7268	119	23.97	70.97	22.04
MC.(%)	7.53	7.53	7.53	7.53	6.77	6.77	-	5.91	-
averg.	30.58	10.39	37.43	0.86	7505	120	25.03	69.87	22.88
SD.	2.03	0.75	1.03	0.01	335	1.91	1.50	1.56	1.19
averg. MC.(%)	7.33	7.33	7.33	7.33	6.58	6.58	-	5.55	-

Table A-9 Testing properties of Para rubberwood-Epoxy resins Composites H

Dimensional Stability					Mechanical Properties				
Sample/piece unit	Polymer Loading %	Water abrorption %	ASE %	Specific gravity g/cm3	Modulus of elastici MPa	Flexure stress MPa	Polymer Loading %	Compression N/mm2	Polymer Loading %
1/1	30.71	12.34	37.04	0.86	-	116	30.02	73.75	33.50
1/2	32.09	10.79	35.56	0.83	5295	117	29.90	70.55	34.10
1/3	30.94	10.24	32.25	0.85	5094	107	31.50	72.56	34.20
1/4	30.11	9.68	31.15	0.84	-	-	28.56	67.55	34.15
1/5	30.35	10.67	40.46	0.83	5532	105	32.50	71.25	34.30
averg.	30.84	10.74	35.29	0.84	5307	111	30.50	71.13	34.05
MC.(%)	5.98	5.98	5.98	5.98	7.53	7.53	-	7.26	-
2/1	30.50	9.25	37.50	0.89	5807	112	25.20	67.84	30.25
2/2	31.35	14.74	34.73	0.85	5702	120	26.30	70.84	31.30
3/3	30.60	16.80	31.68	0.81	5628	-	24.50	67.66	30.75
4/4	32.10	14.15	30.10	0.8	5415	114	23.85	60.29	31.20
5/5	30.10	7.71	33.56	0.84	5535	106	22.10	72.55	30.10
averg.	30.93	12.53	33.51	0.84	5617	113	24.39	67.84	30.72
M.C.(%)	7.99	7.99	7.99	7.99	7.83	7.83	-	7.30	-
averg.	30.89	11.64	34.40	0.84	5462	112	27.44	69.48	32.39
SD.	0.06	1.26	1.26	0.00	219	1.24	4.32	2.33	2.35
averg.M.C.(%)	6.99	6.99	6.99	6.99	7.63	7.68	-	7.28	-

Table A-10 Testing properties of Para rubberwood-Epoxy resins Composites I

Dimensional Stability					Mechanical Properties				
Sample/piece unit	Polymer Loading %	Water abrorption %	ASE %	Specific gravity g/cm3	Modulus of elastici MPa	Flexure stress MPa	Polymer Loading %	Compression N/mm2	Polymer Loading %
1/1	38.54	9.99	39.58	0.82	6463	138	22.50	77.56	28.10
1/2	35.16	9.78	37.24	0.81	-	143	21.70	80.79	27.50
1/3	32.07	10.55	38.41	0.74	7807	138	20.80	75.68	26.58
1/4	33.58	11.37	36.75	0.78	7585	140	19.95	76.85	30.55
1/5	36.43	8.95	37.33	0.86	6857	137	23.55	79.92	25.95
averg.	35.16	10.13	37.86	0.80	7178	139	21.70	78.16	27.74
MC.(%)	6.98	6.98	6.98	6.98	6.54	6.54	-	6.00	-
2/1	34.20	11.10	40.66	0.82	6958	139	17.32	67.85	31.80
2/2	33.50	10.24	42.50	0.85	6846	146	18.50	70.84	30.90
3/3	32.10	9.56	38.90	0.87	6785	141	19.75	67.65	29.65
4/4	30.77	12.15	39.80	0.89	7051	138	20.35	69.55	33.55
5/5	37.50	11.25	40.77	0.36	7158	140	21.50	72.91	32.77
averg.	33.61	10.86	40.53	0.85	6960	141	19.48	69.76	31.73
MC.(%)	7.10	7.10	7.10	7.10	6.28	6.28	-	6.12	-
averg.	34.39	10.49	39.19	0.83	7069	140	20.59	73.96	29.74
SD.	1.09	0.52	1.88	0.04	154	1.13	1.57	5.94	2.83
averg.M.C.(%)	7.04	7.04	7.04	7.04	6.41	6.41	-	6.06	-

Table A-11 Testing properties of Para rubberwood-Epoxy resins Composites J

Dimensional Stability					Mechanical Properties				
Sample/piece unit	Polymer Loading %	Water abrprption %	ASE %	Specific gravity g/cm3	Modulus of elasticity MPa	Flexure stress MPa	Polymer Loading %	Compression N/mm2	Polymer Loading %
- 1/1	10.92	16.41	26.34	0.68	3954	86	16.10	47.64	16.21
1/2	11.76	15.79	23.85	0.70	3756	81	15.50	48.22	15.75
1/3	12.02	14.66	25.90	0.72	4055	88	17.10	50.59	14.50
1/4	11.98	13.69	29.28	0.67	3258	80	14.20	52.66	12.35
1/5	10.55	17.85	27.95	0.70	3578	90	13.50	55.45	11.66
averg.	11.45	15.68	26.66	0.69	3720	85	15.28	50.91	14.09
M.C.(%)	8.96	8.96	8.96	8.96	6.09	6.09	-	7.92	-
2/1	8.60	20.85	25.71	0.82	3095	87	10.57	50.38	12.65
2/2	9.73	15.72	24.23	0.75	4125	89	12.50	49.15	13.10
3/3	8.10	16.55	25.46	0.76	4085	90	13.10	56.25	10.65
4/4	7.95	17.28	23.35	0.82	3055	82	10.65	57.85	11.65
5/5	10.85	19.55	22.85	0.8	3156	95	11.20	58.10	9.85
averg.	9.05	17.99	24.32	0.79	3503	89	11.60	54.35	11.58
MC.(%)	7.96	7.96	7.96	7.96	8.54	8.54	-	8.90	-
averg.	10.25	16.84	25.49	0.74	3612	87	13.44	52.63	12.84
SD.	1.70	1.63	1.66	0.07	153	2.47	2.60	2.43	1.78
averg.M.C.(%)	8.46	8.46	8.46	8.46	7.32	7.32	-	8.41	-

Table A-12 Testing properties of Para rubberwood-Epoxy resins Composites K

Dimensional Stability					Mechanical Properties				
Sample/piece unit	Polymer Loading %	Water abrorption %	ASE %	Specific gravity g/cm3	Modulus of elasticit MPa	Flexure stress MPa	Polymer Loading %	Compression N/mm2	Polymer Loading %
1/1	57.62	9.35	27.88	0.90	4389	117	31.10	57.88	42.69
1/2	52.62	7.94	26.65	0.99	4429	126	30.70	58.71	40.50
1/3	45.03	11.44	30.71	0.92	4050	121	32.10	64.84	38.90
1/4	58.77	8.56	28.35	1.01	4287	115	29.50	69.64	35.95
1/5	50.85	10.25	25.95	0.99	4125	109	33.50	60.77	33.56
averg.	52.98	9.51	27.91	0.96	4256	118	31.38	62.37	38.32
MC.(%)	8.22	8.22	8.22	8.22	7.15	7.15	-	7.94	-
2/1	49.95	10.85	30.61	0.92	4541	121	36.35	66.29	45.10
2/2	52.65	9.38	29.55	0.93	4658	115	34.50	67.07	40.20
3/3	50.66	11.55	26.43	0.98	4985	109	33.45	64.25	39.95
4/4	44.85	13.85	31.66	0.95	4255	130	32.60	62.55	41.25
5/5	47.65	15.66	33.55	0.9	4125	125	30.20	60.80	43.50
averg.	49.15	12.26	30.36	0.94	4513	120	33.42	64.19	42.00
MC.(%)	8.21	8.21	8.21	8.21	7.13	7.13	-	7.92	-
averg.	51.07	10.88	29.13	0.95	4384	119	32.40	63.28	40.16
SD.	2.71	1.94	1.73	0.02	182	1.70	1.44	1.29	2.60
averg.M.C.(%)	8.22	8.22	8.22	8.22	7.14	7.14	-	7.93	-

APPENDIX B

MICROSCOPIC STRUCTURE PICTURES AND CHART OF PARA RUBBER WOOD

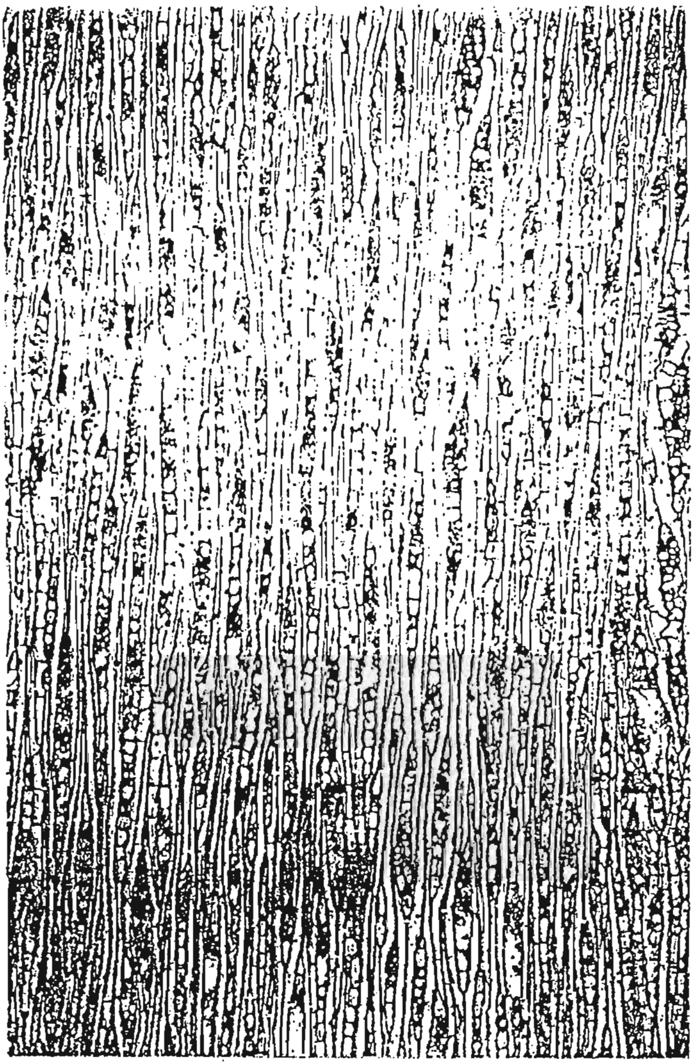


Fig. B-1 Tengential sides structure photo from slides.

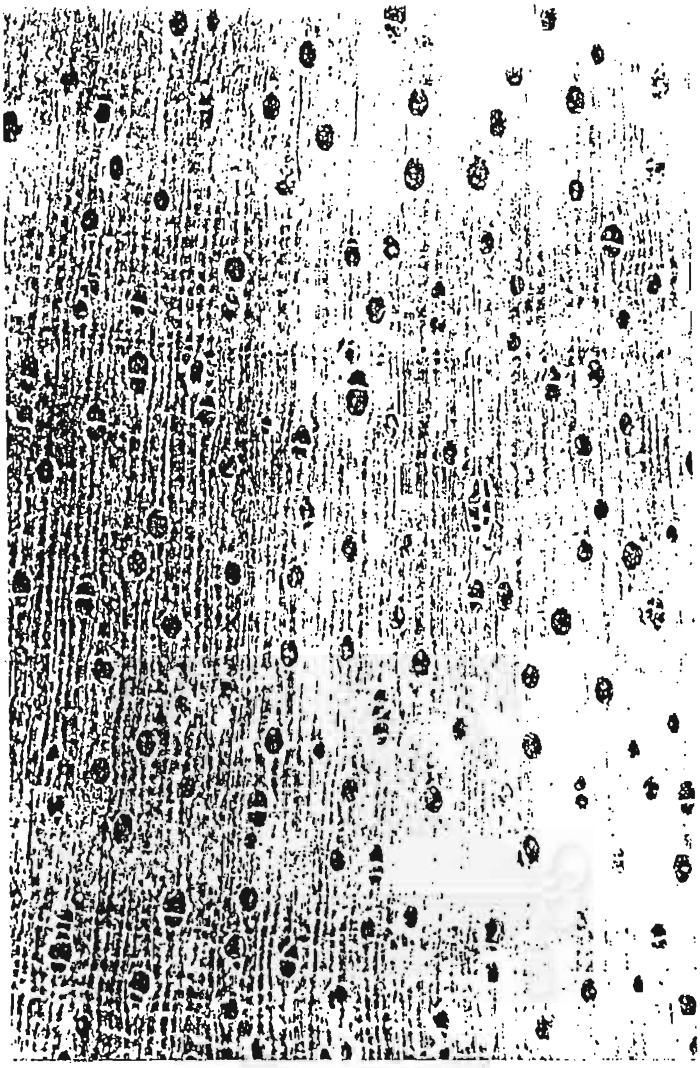


Fig. B-2 Cross section structure photo from wood specimens.

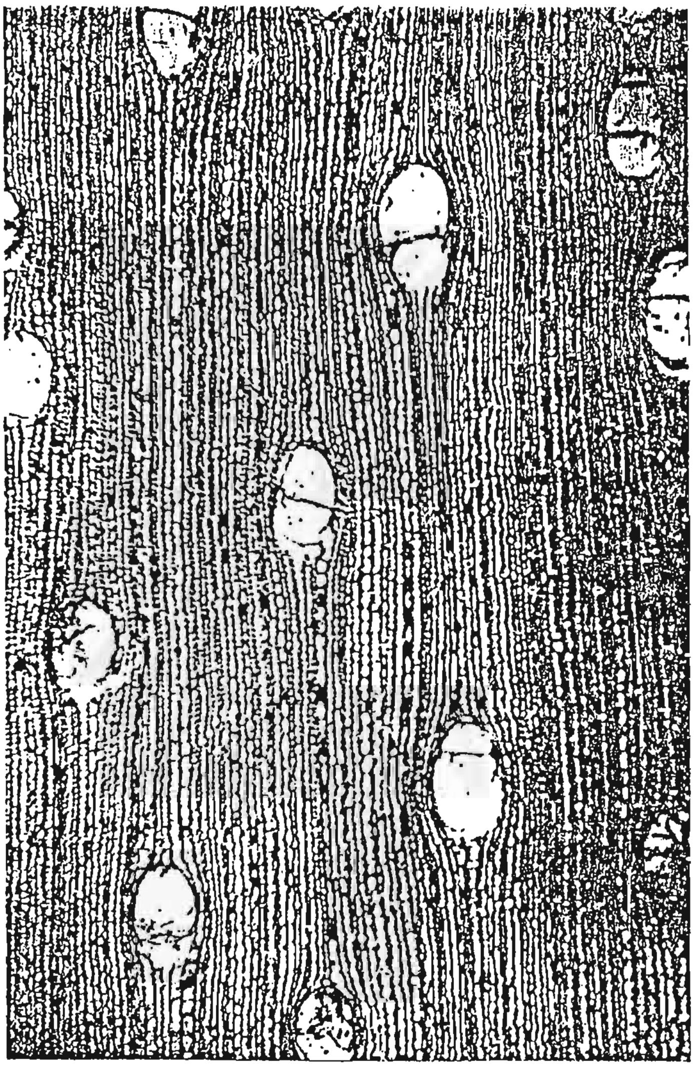


Fig. B-3 Cross section structure photo from slides.

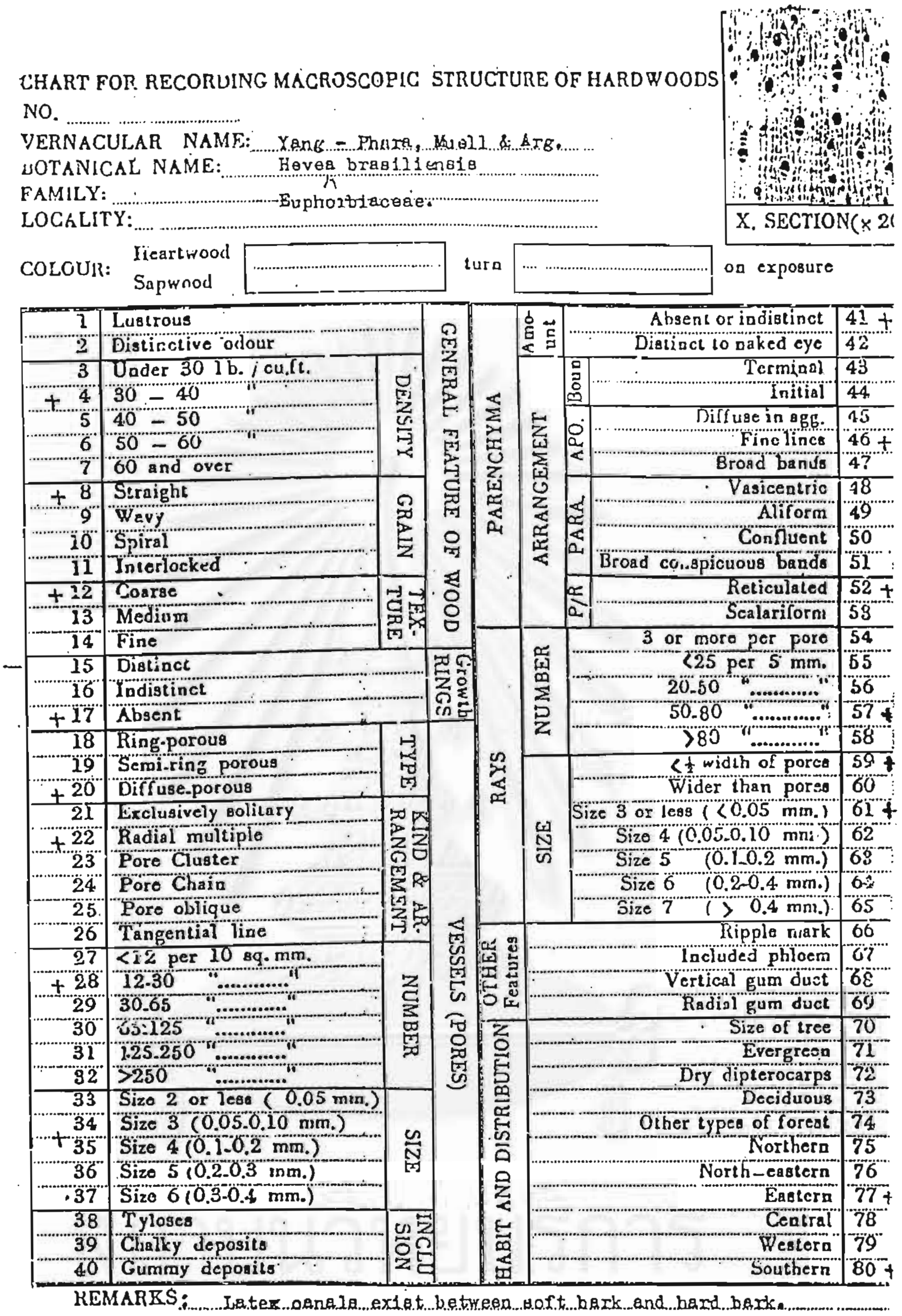


CHART FOR RECORDING MACROSCOPIC STRUCTURE OF HARDWOODS

NO. ....
VERNACULAR NAME: Yang - Phara, Muell & Arg.
BOTANICAL NAME: Hevea brasiliensis
FAMILY: Euphorbiaceae.
LOCALITY: ....

COLOUR: Heartwood / Sapwood .... turn .... on exposure

X. SECTION(× 2

	1	Lustrous		GENERAL FEATURE OF WOOD
	2	Distinctive odour		
	3	Under 30 lb. / cu.ft.	DENSITY	
+	4	30 – 40 "		
	5	40 – 50 "		
	6	50 – 60 "		
	7	60 and over		
+	8	Straight	GRAIN	
	9	Wavy		
	10	Spiral		
	11	Interlocked		
+	12	Coarse	TEX-TURE	
	13	Medium		
	14	Fine		
—	15	Distinct	Growth RINGS	
	16	Indistinct		
+	17	Absent		
	18	Ring-porous	TYPE	VESSELS (PORES)
	19	Semi-ring porous		
+	20	Diffuse-porous		
	21	Exclusively solitary	KIND & AR-RANGEMENT	
+	22	Radial multiple		
	23	Pore Cluster		
	24	Pore Chain		
	25	Pore oblique		
	26	Tangential line		
	27	<12 per 10 sq. mm.	NUMBER	
+	28	12-30 "..........."		
	29	30-65 "..........."		
	30	65-125 "..........."		
	31	125-250 "..........."		
	32	>250 "..........."		
	33	Size 2 or less (0.05 mm.)	SIZE	
	34	Size 3 (0.05-0.10 mm.)		
+	35	Size 4 (0.1-0.2 mm.)		
	36	Size 5 (0.2-0.3 mm.)		
	37	Size 6 (0.3-0.4 mm.)		
	38	Tyloses	INCLUSION	
	39	Chalky deposits		
	40	Gummy deposits		

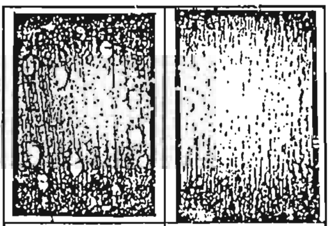
PARENCHYMA	Amount		Absent or indistinct	41	+
			Distinct to naked eye	42	
	ARRANGEMENT	Boun	Terminal	43	
			Initial	44	
		APO.	Diffuse in agg.	45	
			Fine lines	46	+
			Broad bands	47	
		PARA	Vasicentric	48	
			Aliform	49	
			Confluent	50	
			Broad conspicuous bands	51	
		P/R	Reticulated	52	+
			Scalariform	53	
RAYS	NUMBER		3 or more per pore	54	
			<25 per 5 mm.	55	
			20-50 "..........."	56	
			50-80 "..........."	57	+
			>80 "..........."	58	
	SIZE		<½ width of pores	59	+
			Wider than pores	60	
			Size 3 or less (<0.05 mm.)	61	+
			Size 4 (0.05-0.10 mm.)	62	
			Size 5 (0.1-0.2 mm.)	63	
			Size 6 (0.2-0.4 mm.)	64	
			Size 7 (> 0.4 mm.)	65	
OTHER Features			Ripple mark	66	
			Included phloem	67	
			Vertical gum duct	68	
			Radial gum duct	69	
HABIT AND DISTRIBUTION			Size of tree	70	
			Evergreen	71	
			Dry dipterocarps	72	
			Deciduous	73	
			Other types of forest	74	
			Northern	75	
			North-eastern	76	
			Eastern	77	+
			Central	78	
			Western	79	
			Southern	80	+

REMARKS: Latex canals exist between soft bark and hard bark.

Fig.B-4 Chart for recording macroscopic structure of Para rubberwood (1)

CHART FOR RECORDING MICROSCOPIC STRUCTURE OF HARDWOODS

NO.
VERNACULAR NAME: Yang - Phara
BOTANICAL NAME: Hevea brasiliensis, Muell & Arg.
FAMILY: Euphorbiaceae.
LOCALITY:


X. SECTION (x 35)
T. SECTION (x 35)

	1	Ring porous	TYPE		VESSELS
	2	Semi-ring porous			
+	3	Diffuse porous			
+	4	Solitary pore	Arrangement		
+	5	Pore multiple			
	6	Pore chain			
	7	Pore oblique			
	8	Tangential line			
	9	Pore cluster			
305	10	Av. dia. of pores (μ)	Size		
876	11	Av. length of vessels (μ)			
	12	Spiral thickening	CELL WALL STRUCTURE		
+	13	Round or polygonal	INTERVESSEL PITS	Shape	
	14	Linear			
	15	Vestured			
	16	Opposite		Pitting	
+	17	Alternate			
	18	Scalariform			
+	19	Simple	Perforation		
	20	Scalariform			
	21	Reticulate			
+	22	Tylosee	Inclu		
	23	Gummy deposits			
	24	Vasicentric			Tracheids
	25	Vascular			
	26	Fiber tracheids	Type		FIBERS
+	27	Libriform fibers			
	28	Av. thickness (μ)	Size		
30	29	Av. diameter (μ)			
605	30	Av. length (μ)			
	31	Septate	Modification		
	32	Gelatinous			
	33	Spiral thickening			
	34	Pith flecks			OTHER Features
	35	Traumatic gum ducts			
	36	Included phloem			
	37	Storied structure			

LONGITUDINAL PARENCHYMA	ARRANGEMENT	APO.	Diffuse	38	
			Diffuse in aggregates	39	+
			Fine lines	40	+
			Broad bands	41	
			Reticulated	42	+
		PARA.	Scanty	43	+
			Unilaterally	44	
			Vasicentric	45	+
			Aliform	46	
			Aliform-confluent	47	
			Confluent	48	
			Broad conspicuous bands	49	
		Boun	Initial	50	
			Terminal	51	+
			Number of cells in strand	52	4
			Fusiform parenchyma cells	53	
	Inclusion		Crystal	54	
			Infiltration	55	
WOOD RAYS			Number per mm. tangentially	56	
	KIND		Simple	57	+
			Aggregate	58	
			Oak-type	59	
	COMPOSITION	Uni-only	Homogeneous	60	
			Heterogeneous	61	
		UNI. & MULTI.	Homogeneous	62	
			Heterogeneous type I	63	+
			Heterogeneous type II	64	
			Heterogeneous type III	65	+
	Size		Av. width (μ)	66	45
			Av. height (μ)	67	15
	Inclusion		Crystal	68	
			Oil cells	69	
			Infiltration	70	+
NORMAL gum ducts	Kind		Longitudinal	71	
			Transverse	72	
			Number per sq. mm.	73	
			Av. tangential diameter	74	

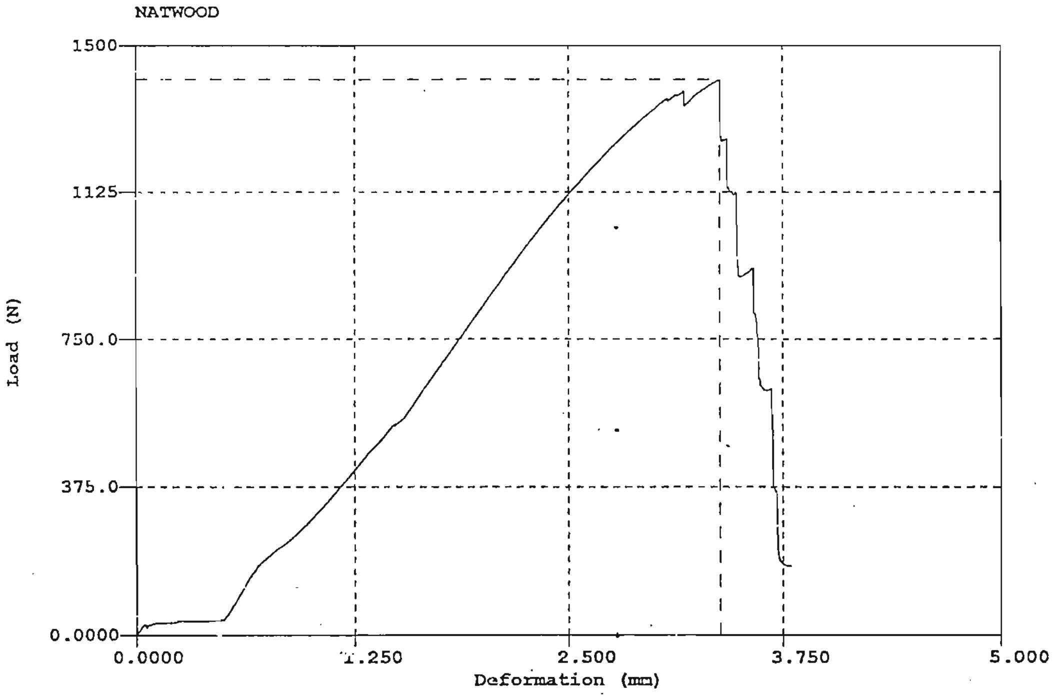
REMARKS:

Fig.B-5 Chart for recording macroscopic structure of Para rubberwood (2)

APPENDIX C

GRAPHS OF TESTING RESULTS

ASTM D 3043
Speed 1mm/min
Span 64 mm



Fm	Def @ Max Load	E	3 Point Bend	Sample Width	Sample Thick'	Batch Number	Job Number
N	mm	N/mm²	N/mm²	mm	mm	-	-
1414	3.383	5322	105.4	25.5500	7.10000	natwood	5

Figure C-1 Graph of MOE testing of natural rubberwood.

Product Code : NAT.RW.
Batch Reference : ISO3787

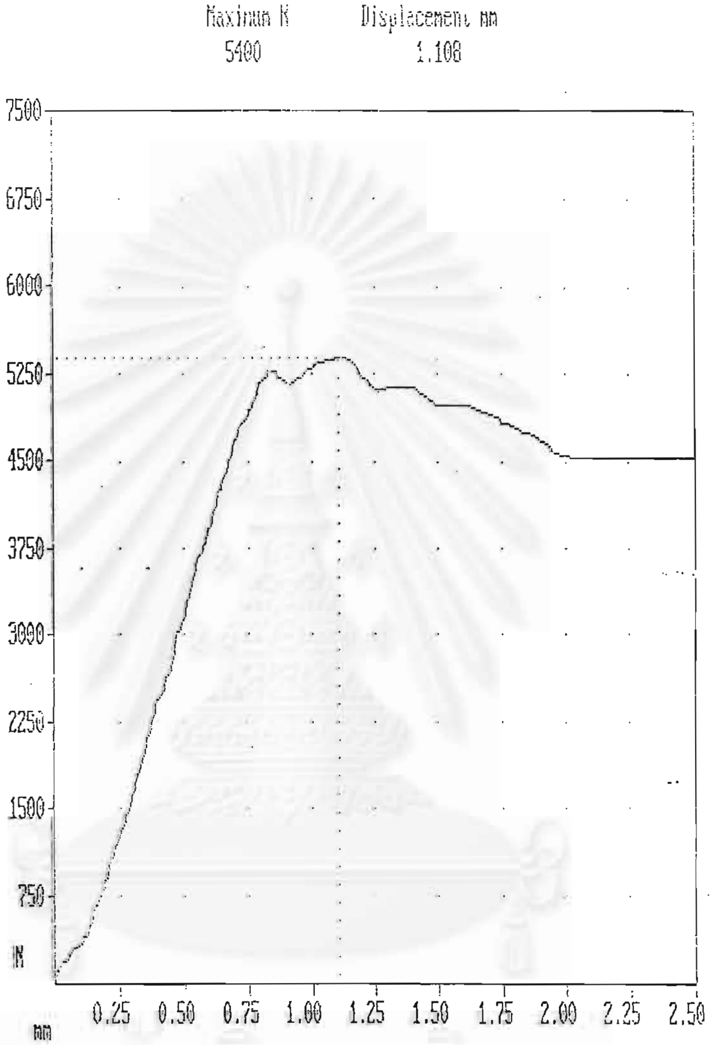
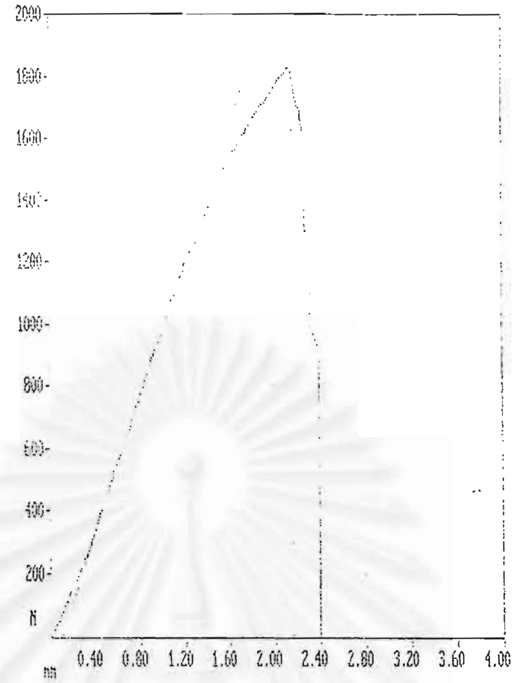


Figure C-2 Graph of compression testing of natural rubberwood.

Product Code : WPC..
Batch Reference : H.D.75%

	Elastic Mod MPa	Flex.Str. Max. MPa	Flex.Str. Con.P MPa	Deflect. @Break mm
Thick. 6.53 mm Width 26.1 mm	9806	159.3	-	2.31



Product Code : WPC
Batch Reference : H.D.75%

Maximum N	Displacement mm
8030	1.382

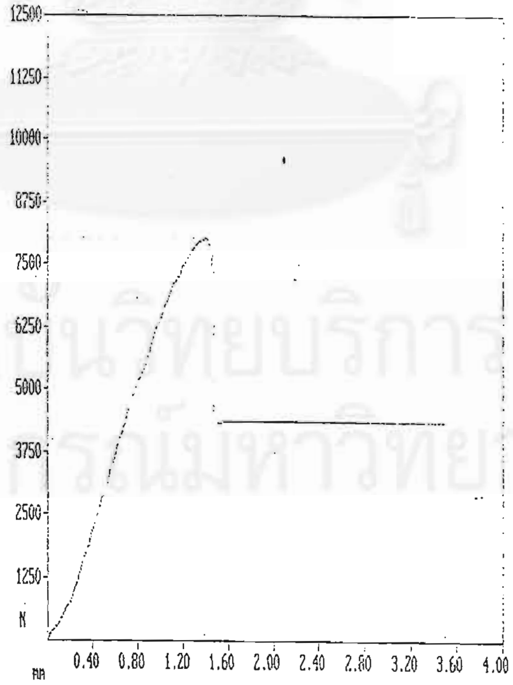


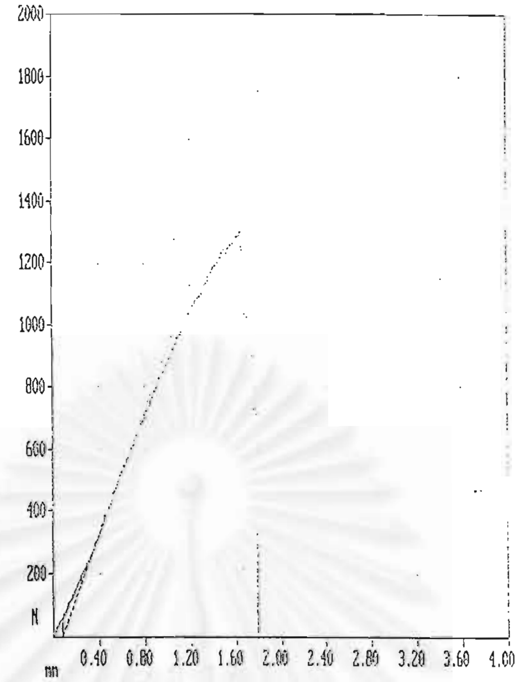
Figure C-3 Graph of MOE testing (up) and compression testing (low) of WPC, prepared from prepolymer mixtures containing reactive diluent.

Product Code : WPCBB
Batch Reference : ASTM3043

Page - 3

[Test No. 2]

	Elastic Mod MPa	Flex.Str. Max. MPa	Flex.Str. Con.P MPa	Deflect. @Break mm
Thick. 6.62 mm				
Width 25.6 mm	8685	111.9	-	1.718



Product Code : WPCBB
Batch Reference : ASTM

Page - 3

[Test No. 5]

Maximum N	Displacement mm
7140	1.275

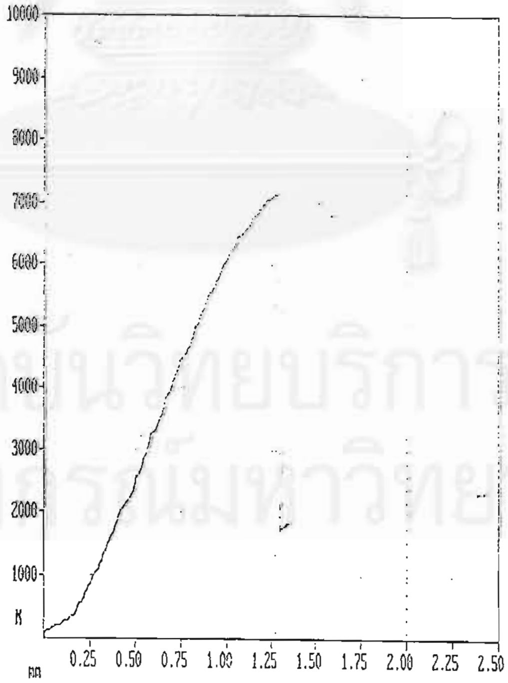
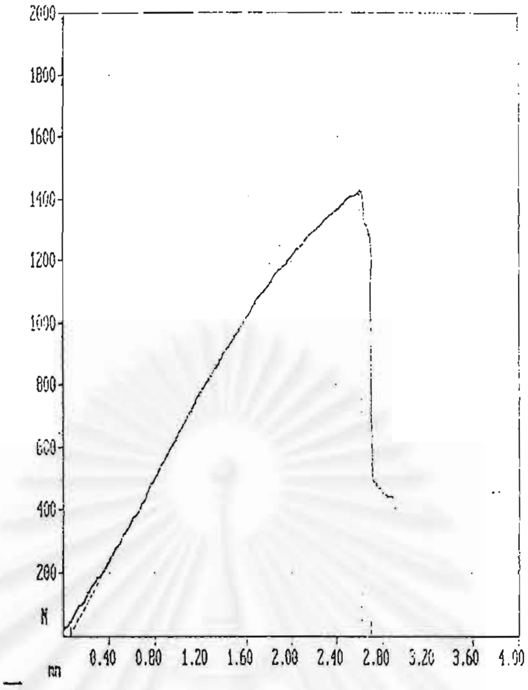


Figure C-4 Graph of MOE testing (up) and compression testing (low) of WPC, prepared from prepolymer mixtures containing 27 phr. hardener.

Product Code : WPCGG
Batch Reference : ASTMD3043

Page - 2

Elastic Mod Flex.Str. Flex.Str. Deflect. [Test No. 1]
Thick. 6.20 mm MPa Max. MPa Con.P MPa @Break mm
Width 25.76 mm 7240 140.0 - 2.64



Product Code : WPCAA
Batch Reference : ASTM

Page - 3

[Test No. 2]
Maximum N Displacement mm
7340 1.172

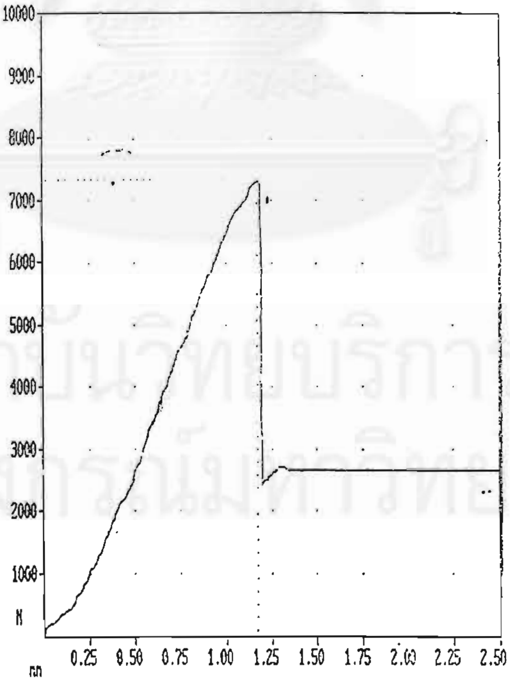


Figure C-5 Graph of MOE testing (up) and compression testing (low) of WPC, prepared from 60 minutes soaking times.

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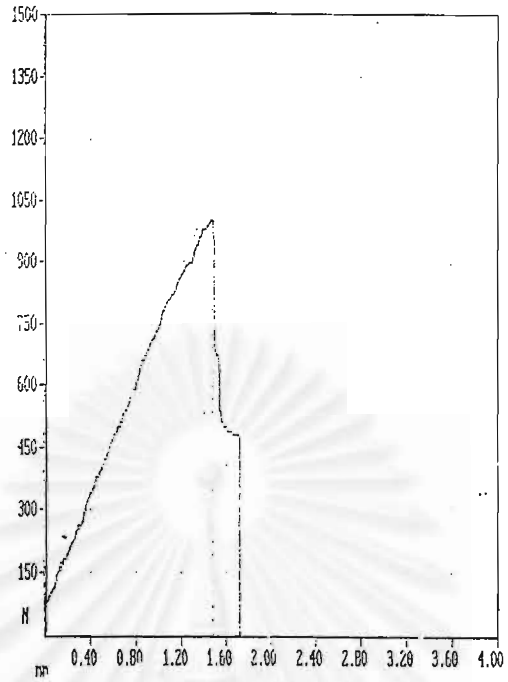
Product Code : WPH38D30                                Page - 6
Batch Reference : ASTM D3043

               Elastic Mod  Flex.Str.  Flex.Str.  Deflect. [ Test No.  5 ]
Thick. 5.72 mm         MPa  Max. MPa  Con.P MPa  @Break mm
Width  25.24 mm       9481     117.7         -      1.810
```



```
Product Code : WPC                                     Page - 4
Batch Reference : ISO3787

                                              [ Test No.  4 ]
                    Maximum N      Displacement mm
                    7060               1.064
```

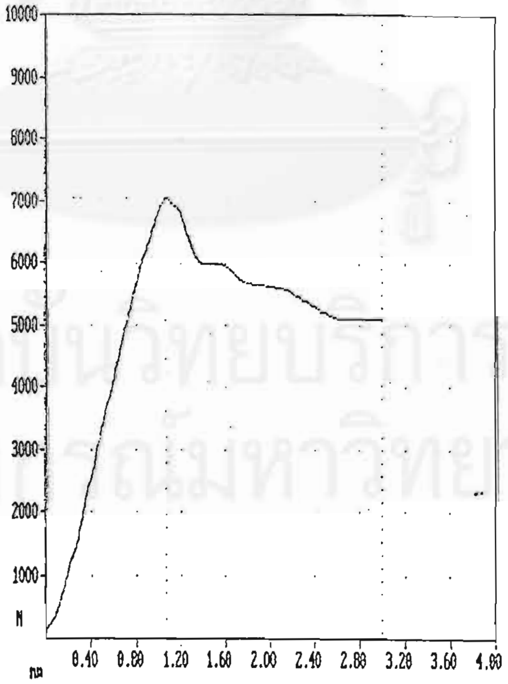


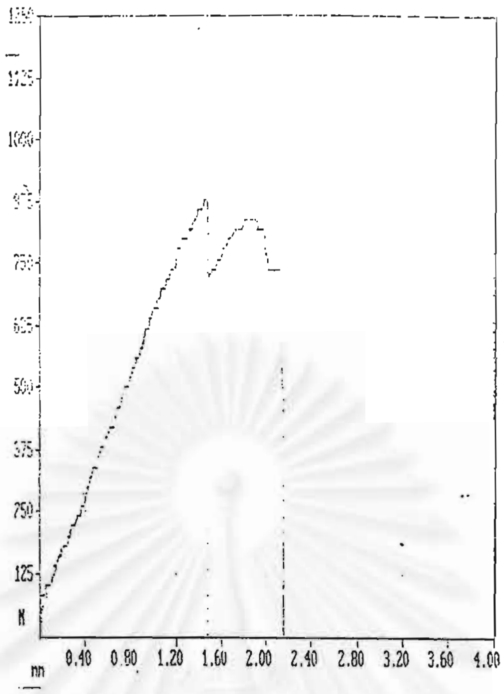
Figure C-6 Graph of MOE testing (up) and compression testing (low) of WPC, prepared from 2 hours evacuating times.

Product Code : WPH36D30
Batch Reference : ASTM D3043

Page - 3

Elastic Mod Flex.Str. Flex.Str. Deflect. | Test No. 2 |

	Elastic Mod MPa	Flex.Str. Max. MPa	Flex.Str. Con.F MPa	Deflect. @break mm
Thick. 5.58 mm				
Width 25.74 mm	8803	106.8	-	2.23



Product Code : WPCH36
Batch Reference : ISO3/87

Page - 3

[Test No. 2]

Maximum N	Displacement mm
7253	1.416

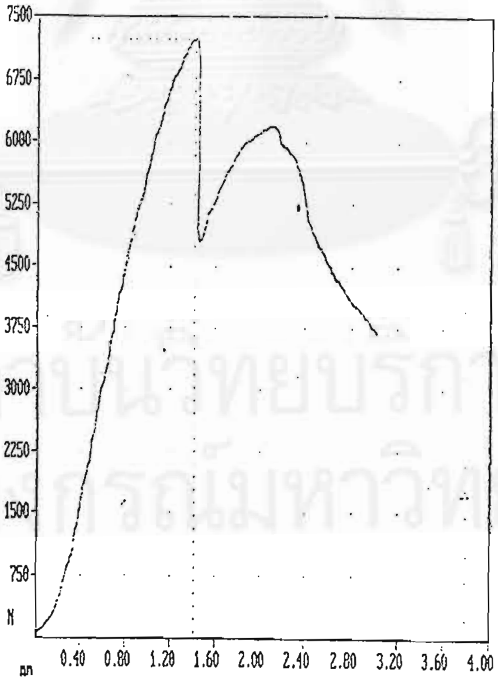


Figure C-7 Graph of MOE testing (up) and compression testing (low) of WPC, prepared from 500 mmHg. evacuating pressure.

VITA

Miss Chalengjit Rungvichaniwat was born on July 12, 1966 in Yala province. She received Bachelor's Degree of Science, Major Chemistry from Prince of Songkla University in 1989. She worked for Beauty Services Co., Ltd. for 3 years. Later she worked for Thai Modern Plastic Industry Public Co., Ltd. for 5 years. After that, she has been a graduated student in the Program of Petrochemistry and Polymer Science, Graduate School, Chulalongkorn University since 1997.