STUDY ON MECHANICAL, SOUND ABSORPTION AND THERMAL INSULATION PROPERTIES OF PARTICLEBOARD MADE FROM BAGASSES AND POLYSTYRENE FOAM BY USING UREA-FORMALDEHYDE AND PHENOL-FORMALDEHYDE AS BINDERS

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A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENT FOR THE DEGREE OF
MASTER OF SCIENCE IN POLYMER TECHNOLOGY
SCHOOL OF GRADUATE STUDIES
KING MONGKUT'S INSTITUTE OF TECHNOLOGY LADKRABANG
2005

ISBN-974-15-1432-8

หัวข้อวิทยานิพนธ์	**การศึกษาสมบัติเชิงกล การดูดซับเสียงและความเป็นฉนวนความร้อนของแผ่นชิ้นไม้อัดทำจากชานอ้อยและโฟมพอลิสไตรีนโดยใช้ยูเรียฟอร์มาลดีไฮด์และฟีนอลฟอร์มาลดีไฮด์เป็นตัวประสาน**
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บทคัดย่อ

วิทยานิพนธ์เล่มนี้มีจุดมุ่งหมายในการศึกษาการเตรียมแผ่นชิ้นไม้อัดที่ทำจากชานอ้อยและวัสดุเหลือทิ้งโฟมพอลิสไตรีน กาวสองชนิดถูกนำมาใช้เป็นตัวประสาน ได้แก่ ยูเรีย-ฟอร์มาลดีไฮด์และฟีนอลฟอร์มาลดีไฮด์ ตัวแปรหลายชนิดได้แก่ ปริมาณกาว อัตราส่วนชานอ้อยต่อโฟมพอลิสไตรีน ขนาดของโฟมพอลิสไตรีน เวลาในการแข็งตัว ความหนาแน่นของแผ่น การมีอยู่และการไม่มีอยู่ของโฟมพอลิสไตรีนในแผ่นและขนาดของชานอ้อยถูกตรวจสอบด้วยเช่นกัน ผลที่ได้ระบุว่าสมบัติส่วนใหญ่ของแผ่นชิ้นไม้อัดที่ใช้กาวฟีนอลฟอร์มาลดีไฮด์ให้ผลดีกว่าแผ่นชิ้นไม้อัดที่ใช้กาวยูเรีย-ฟอร์มาลดีไฮด์ เช่น ความทนทานต่อการดูดซับน้ำ ความทนทานต่อการพองตัวทางความหนา ความแข็งแรงหักงอ และการดูดซับเสียง ยกเว้นค่าการนำความร้อน

ผลการทดลองที่ได้พบว่าการดูดซับน้ำและการพองตัวทางความหนาลดลงเมื่อปริมาณชานอ้อยลดลงและเวลาในการแข็งตัวนานขึ้น ยิ่งไปกว่านั้นการเพิ่มขึ้นของปริมาณกาว ความหนาแน่นของแผ่น (ยกเว้นในกรณีสมบัติการพองตัวทางความหนา) ขนาดของชานอ้อยและโฟมพอลิสไตรีนทำให้การดูดซับน้ำและการพองตัวทางความหนาลดลงด้วย ในทางตรงกันข้ามความแข็งแรงหักงอเพิ่มขึ้นตามปริมาณที่เพิ่มขึ้นของโฟมพอลิสไตรีน เวลาในการแข็งตัว กาว ความหนาแน่นของแผ่น การมีอยู่ของโฟมพอลิสไตรีนในแผ่นและขนาดของชานอ้อย แผ่นชิ้นไม้อัดความหนาแน่น 0.3 กรัมต่อลูกบาศก์เซนติเมตร กาว 7% เวลา 15 นาทีในการแข็งตัวและอัตราส่วนชานอ้อยต่อโฟมพอลิสไตรีนที่ 85/15 โดยน้ำหนัก ให้ค่าการดูดซับเสียงสูงที่สุด ผลที่ได้แสดงให้เห็นว่าสมบัติฉนวนความร้อนขึ้นอยู่กับความหนาแน่น ความหนาแน่นที่ต่ำที่สุด 0.1 กรัมต่อลูกบาศก์เซนติเมตร ให้ค่าความเป็นฉนวนความร้อนสูงที่สุด

โดยสรุป ข้อมูลที่ได้รับจากตัวแปรและสภาวะต่างๆ แสดงให้เห็นว่าแผ่นชิ้นไม้อัดเตรียมจากส่วนผสมของชานอ้อยและโฟมพอลิสไตรีนสามารถใช้ทดแทนได้ทั้งแผ่นยิปซั่มทางการค้าและแผ่นชิ้นไม้อัดทางการค้าทั่วๆไปในบางลักษณะ ชนิดและปริมาณกาวสำหรับแผ่นชิ้นไม้อัดขึ้นอยู่กับประเภทของผลิตภัณฑ์ที่ต้องการ ยิ่งไปกว่านั้น แผ่นชิ้นไม้อัดที่เตรียมขึ้นนี้อาจเป็นทางเลือกที่ดีในการจัดการวัสดุเหลือทิ้งทางการเกษตรและวัสดุเหลือทิ้งโฟมพอลิสไตรีนจากสิ่งแวดล้อมและเป็นการเพิ่มมูลค่าให้กับวัสดุเหลือทิ้งอีกด้วย

Thesis	Study on Mechanical, Sound Absorption and Thermal Insulation Properties of Particleboard made from Bagasses and Polystyrene Foam by Using Urea-Formaldehyde and Phenol-Formaldehyde as Binders
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Programme	Polymer Technology
Year	2005
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ABSTRACT

This thesis is aimed at studying the preparation of particleboard from bagasses (BG) and expanded polystyrene foam (EPS) waste. Two kinds of adhesives, i.e., Urea-formaldehyde and Phenol-formaldehyde, were used as binders. Several parameters, i.e., adhesive quantities, ratios of BG/EPS, EPS sizes, curing times, board densities, presence and absence of EPS in board and BG sizes were investigated as well. The results indicated that most properties of PF boards were better than UF boards. Such properties included water absorption resistance, thickness swelling resistance, bending strength, and sound absorption with an exception of thermal conductivity.

The experimental results found that water absorption and thickness swelling decreased with decreased the amount of BG and longer curing time. Moreover, the increment of adhesives, board density (except thickness swelling properties), BG size and EPS also resulted in the reduction of water absorption and thickness swelling. On the other hand, bending strength increased in relations to the amount of EPS, curing time, adhesive, board density, presence of EPS in board and BG size. Particleboards density of 0.3 g/cm^3 with 7% adhesive, 15 minutes curing time and BG/EPS ratio at 85/15 wt/wt, provided the highest sound absorption. The result suggested that thermal insulation property depended on density. The lowest density of 0.1 g/cm^3 yielded the highest thermal insulation.

In summary, data received from several parameters and conditions indicated that particleboards prepared from the mixtures of BG and EPS can be used to substitute for both

commercial gypsum boards and general wood particleboards in some aspects. The types and amount of adhesives for particleboard depended on types of products desired. These kinds of particleboards provide good alternatives for the management of agricultural wastes and expanded polystyrene foam waste and also enhance value of the wastes.

ACKNOWLEDGMENT

The completion of thesis study was made possible by a large number of persons who dedicated their time and made available their suggestions. I would like to express my heart-felt and sincere thanks to the following:

- my advisor - Assoc. Prof. Dr.Malinee Chaisuprakitsin for her valuable suggestion, guidance, and encouragement throughout the study;
- Assoc. Prof. Anupong Srongprapa for his supply of the sound absorption apparatus and useful advice about sound wave knowledge.
- Assoc. Prof. Dr. Ittipol Jangchud, and Assist. Prof. Dr. Jutarat Prachayawarakorn for their kindness to act as members of the thesis committee.
- Resources Environment Chemistry who allowed me to borrow the sound level meter and TOA-Dovechem Industries Co.,Ltd. for supplying phenol-formaldehyde resin.
- I am most grateful to my parents and friends for their inspiration and encouragement.

Last, but not least, I also would like to express my thanks to those who are not referred to, for their continuous assistance, cooperation, and inspiration for the research.

Thanawan Apichatsopit

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ABBREVIATIONS

	Letter
Area bounded by the middle of the guard/center gap (m^2)	A
Bagasses	BG
Constant value (dl)	k
Density (g/cm^3)	D
Expanded polystyrene	EPS
Heater power (Watt)	$\dot{Q}$
Increasing bending distance in the range of linear line of graph (N)	ΔS
Increasing load in the range of linear line of graph (N)	ΔW
Isocyanate	IC
Mass (g)	m
Mass after water absorption (g)	m_2
Mass before water absorption (g)	m_1
Maximum load (N)	P
Methyl diphenyl diisocyanate	MDI
Melamine-formaldehyde	MF
Modulus of Elasticity (Mpa)	MOE
Modulus of elasticity (Pascal)	E
Modulus of Rupture (Mpa)	MOR
Phenol-formaldehyde	PF
Sound absorption coefficient	a
Soybean flour	SF
Soybean protein isolate	SPI
Span (mm)	L
The average temperature drop through the test piece thickness (K)	ΔT
The average thickness of the test piece (m)	d
Thermal conductivity of convection (W/m K)	λc
Thermal conductivity of gascous (W/m K)	λg
Thermal conductivity of radiation (W/m K)	λr

ABBREVIATIONS (TO)

	Letter
Thermal conductivity of solid (W/m K)	λ_s
Thermal transmission	R
Thickness after water absorption (mm)	t_2
Thickness before water absorption (mm)	t_1
Thickness of test piece (mm)	t
Total thermal conductivity (W/m K)	λ
Urea-formaldehyde	UF
Velocity of sound (m/s)	v
Volume (cm^3)	V
Width of test piece (mm)	b

CHAPTER 1

INTRODUCTION

1.1 Research Motivation

Shortage of forestry resources has become an emerging problem worldwide. People are looking for materials to substitute for wood-based materials, such as particleboard, plywood, medium density fiber board (MDF), etc. The construction material industries has shown increasing interest in the production of particleboard from agricultural lignocellulosic fiber residues. Examples of such raw materials include bagasses, rice straw, etc. Such materials can be easily crushed to ships or particles. Bagasses are one of the favorite raw materials, for particleboard manufacturing as it is the effect of by-product utilization on the profitability of sugar production. The amount of bagasse derived from sugar production, is around 25% of sugar cane. In fact, the amount of sugar cane planting is of high amount annually resulting in high leftovers of bagasses as shown in Figure 1.1. Generally, 30% of them is burnt in low efficiency boilers, 15% of them is used as pulp for producing paper so the remaining of 55% or around 10 million tons in each year is then required to be disposed.

At present, polystyrene foams have stimulated high demands in many applications e.g. packaging, cushioning and insulation due to their low cost, light weight, ease of application and fabrication. Low thermal conductivity, consumer appeal, and mechanical properties such as compressive properties are also factors attracting such high demands. Total worldwide EPS consumption during year 2000 was estimated at around 2,570,000 tons as shown in Figure 1.2. However, it is difficult to degrade such material which has a low recycle. This will consequently lead to environmental pollution.

This study is aimed at using agricultural waste and polystyrene foam waste to prepare particleboards with high sound absorption and low thermal conductivity. Such particleboards can be used as ceiling for constructing a room which is located in noisy environment, instead of general commercial particleboards. This new particleboards will help those working or living in noisy environment to have better well being. They will also reduce energy consumption of building facilities such as air-conditioning. Furthermore, advantages of these particleboards are to reduce agricultural wastes and polystyrene foam waste left in the environment as well as to make use of the waste.

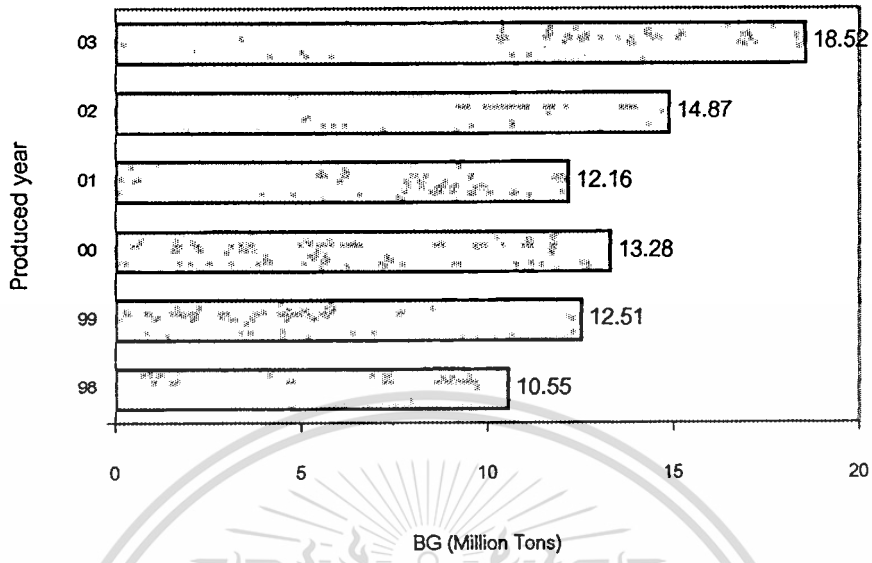


Figure 1.1 Growth of bagasses in Thailand since 1998 until 2003 [1]

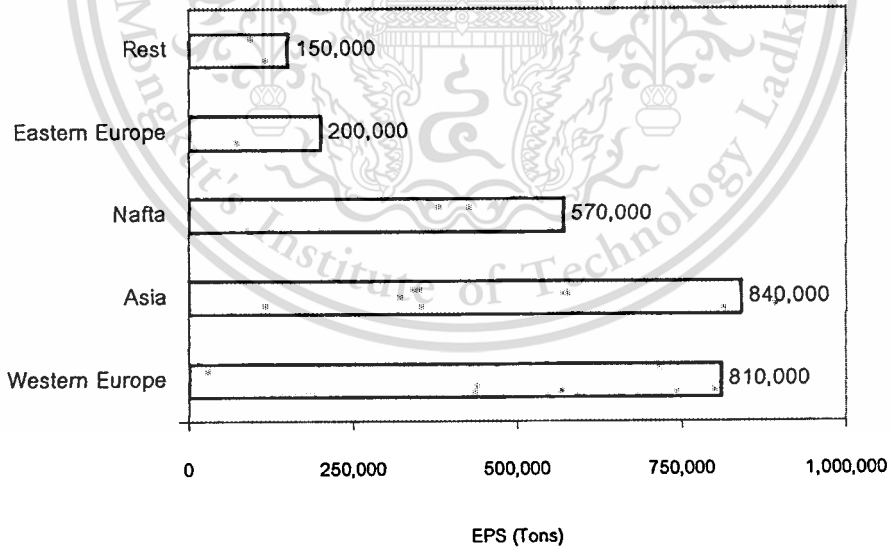


Figure 1.2 Worldwide EPS consumption in year 2000 ; total consumption 2,570,000 tons [2]

1.2 Objectives of the Research

Objectives of this study were as follows.

1. To develop high sound absorption and low thermal conductivity particleboards from the mixture of agricultural wastes and polystyrene foam waste.

2. To study effects of adhesive types on acoustic, thermal, mechanical and physical properties.

3. To investigate several parameters for producing particleboards.

1.3 Scopes of the Research

The study of particleboard development from agricultural wastes, BG, and expanded polystyrene foam waste included the effects of adhesive types i.e. urea-formaldehyde and phenol-formaldehyde on physical and mechanical properties of particleboards. What to be changed included the ratios of BG/EPS, EPS size, curing time, adhesive quantity, board density, presence and absence of EPS in boards and BG size. After the particleboard was prepared, we were then measured acoustic properties (%sound absorption), thermal insulation properties (thermal conductivity), mechanical properties (Modulus of Rupture and Modulus of Elasticity) and physical properties (percentage of water absorption and percentage of thickness swelling).

1.4 Expected Results

1. To obtain a technical guidance on how to produce particleboards from agricultural wastes and polystyrene foam waste.

2. To obtain a new alternative on how to manage agricultural wastes and polystyrene foam waste.

CHAPTER 2

THEORETICAL CONSIDERATIONS AND LITERATURE REVIEWS

2.1 Particleboard Process [3-6]

2.1.1 Particle Preparation

Initially, raw materials are brought to a board plant and placed in some types of storage. If it is relatively small particulate substance that can be used directly in the board process, some types of classification by size may be conducted immediately and the material be fed into the plant. Larger materials must be reduced to flakes, or fibers using a the proper equipment, depending on what type of product being produced.

The particles are next screened to remove excess fines, and all particles removed by hand screening over a 20 mesh screen are discarded. Large amount of very finely divided wood, with a corresponding high surface-area-to-weight ratio, would absorb a disproportionately high amount of resin. In several commercial operations, more of the fine may be left in the furnish, and this can be used for the production of some specific type of boards.

After the particles are prepared, the next typical step is to reduce moisture content to 2-4% in a dryer.

2.1.2 Blending

The furnish then is proceeded to a blender, of which there are many versions. In the blender, resin and wax are applied to the furnish. Additional moisture can also be added if it is needed, as well as a catalyst if required. In some dry-process hardboard plants using liquid phenolic resin, the resin and wax can be added to the raw material before drying. The resin and wax are blended simultaneously with the furnish as it is being generated in the attrition mill. Thus, the attrition mill functions as both a particle generator and a blender. The phenolic resin has a higher curing temperature than the urea resin and then be able to pass through the dryer without being cured. Urea resin cannot be handled in this way, as it will cure out in the dryer. When drying this resin-treated furnish, it is not necessary to go to the very low moisture content of 2 to 4%. The final mat

moisture content, ranging from about 8 to 11%, then becomes the specification; therefore, the raw material is emerging from the dryer.

2.1.3 Mat Formation and Handling

Flakes with resin and wax applied are immediately formed, by hand felting, into mats 15 inch (381 mm) wide by 22 inch (558.8 mm) long and with the proper weight of particles to yield the desired density and thickness as called for in the experimental design. A hinged, bottomless forming frame is used so that when a mat is completed, the latched corner of the frame could be unhooked and the entire frame removed to leave a free standing mat for not pressing. The formed mat, supported and covered by 3/16 inch (4.7 mm) aluminum caul sheets, is transferred to the prepressing stage.

2.1.4 Prepressing

Prior to hot pressing, the mats which loosely formed material is consolidated into a relatively rigid 'cake' by cold pressing in order to reduce their thickness and to make them easier to transport.

2.1.5 Hot Pressing

The pre-formed mats of glued particles and fibres are transferred to the hot press for pressing and curing. This operation is critical and requires carefully controlled heat, pressure and timing.

The thick mats are compressed in the press with thickness controlled either by thickness bars (stops) or other electronic thickness measuring devices. As soon as heat is applied, the glue curing process begins and full pressure is quickly applied to reach the desired thickness before cure. Full pressure at stops is held for the prescribed time then pressure is slowly reduced until the press is opened. Airing cycles are important to allow the steam generated to escape thus preventing "blown boards". Typical pressures are 2-3 MPa, temperature 140-220 °C and press-time 6-15 seconds per mm of board thickness plus the opening/closing times of the press.

Curing of urea formaldehyde resin; during hot pressing, the polymerization and condensation is completed. Some formulae cure at room temperature; other require hot pressing at 99-121 °C. Shortly before the UF solution is sprayed onto the woodfibers for particles and flakes for particleboard, catalyst is added. It is an acid; most UF condense fastest within a pH range of 3-4. Now the UF solution's shelf life is reduced dramatically and measured in hours. In the presence

of heat supplied during pressing, the precondensated UF crosslinks into a solid resin. During the hot pressing, a portion of the excess formaldehyde is emitted. The reaction is reversible too much heat hydrolyses the UF resin into urea and formaldehyde thereby degrading the bond and releasing even more formaldehyde. It is therefore of critical importance to precisely control pressing time and immediately cool the finished panels after completion of the pressing.

Curing of phenol formaldehyde resin; unlike with UF, no catalyst is added to PF. It is delivered as a ready-to-use solution. Most common types of PF require hot pressing at about 127-149 °C. Temperature as high as 204 °C may be used for structural composites. The rate of curing is strongly influenced by the adjunct of sodium hydroxide NaOH: the higher its concentration, the faster the curing. Too high a NaOH adjunct, however, leads to a rather high hygroscopicity (meaning affinity for moisture absorption from the air) causing a swelling of the PF resin upon an increase in the relative humidity of the surrounding air.

Unlike UF, PF's curing is not reversible. The more heat is applied and the longer the pressing lasts, the more complete the crosslinking. In stead of cooling after pressing as is required for UF, it is desirable to keep PF bonded products hot. Release of free formaldehyde is therefore mitigated by hotter and longer pressing within the limits of thermal degradation of the wood itself.

2.1.6 Finishing

The hot boards are removed from the press and further conditioned to equilibrate board moisture content and to stabilise and fully cure the resin. This conditioning usually follows cooling in star coolers for boards with urea-formaldehyde resins. Phenolic bonded particleboard flooring is usually hot stacked for some days to ensure final cure of the resin.

Panels are then trimmed and sanded on both faces to tight thickness tolerances. Sanded sheets are sawn to stock sizes or to suit special orders.

2.2 Fibrous Raw Materials [7]

Sugar cane *(Sacharum officinarum)* belongs to the botanical family of Gramineae. Depending on its geographical place of growth the length is 2 to 6 m. and the stem diameter of 2 to 5 cm. In appearance, especially, the leave are very similar to corn.

Sugar cane thrives in tropical and sub-tropical countries with sufficient humidity. For sugar production, only the stem are utilized, as the leaves are cut off while harvesting the cane. The cane stem residue shows the following composition :

Table 2.1 Composition of cane [7]

Water	75 %
Fibers and pith	11 %
Sugar	13 %
Others	1 %

The chemical composition of the fibrous lignocellulosic residues of sugar cane after crushing and extraction of the juice, i.e. bagasses, as show by Table 2.1 is very similar to wood. Table 2.2 gives a comparison.

Table 2.2 Chemical composition of bagasses and wood [7]

	Bagasses	Beech	Pine
	%	%	%
Cellulose	46	45	42
Lignin	23	23	29
Pentosans and Hexosans	26	22	22
Others	5	10	7

With regard to the structure of the cells, the bagasses consists mainly of sclerenchymatic tissue (fiber) and parenchymatic tissue (pith).

Most of the sclerenchymatic tissue, the fibres, are situated in the outer zones of the cane-stem and in the rind. In the inner parts of the stem the parenchymatic tissue, the so-called "pith" prevails with its characteristic thin cell walls and voluminous cell lumen. The lumen proportion of parenchymatic cells is greater the closer they are to the stem (compare Figure 2.1).

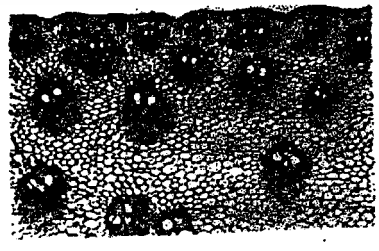


Figure 2.1 Microscopic cross-section of cane, showing rind fibers and pith [7]

The transition from parenchymatic to sclerenchymatic tissue cannot be exactly defined, especially in the outer zones of the stem near the rind, and it is not possible to give an exact classification by weight of the different types of cell. A rough idea is given by Table 2.3.

Table 2.3 Classification by weight of types of cell in bagasses [7]

Rind	40-55 %
Fibers in the inner stem	15-35 %
Pith	20-35 %

The composition by weight of bagasses according to the different types of cells depends very much on the type of cane and the source. The proportion of fiber is comparatively high in climatic zones with cooler seasons. On the other hand in zones with a constant hot and humid climate the fiber content is less and the individual fibers are weaker. As normally in these zones length and diameter of the cane is higher, the percentage of rind compared with the local weight of the sugar cane stem, i.e. the fiber content, is less.

Due to the seasonal nature of the cane harvest, the particleboard mill may have to operate partially on green bagasses, and partially on baled stored material. The green bagasses have high moisture content therefore they have very plastic. Excessively dry bagasses are too brittle and give too much dust and damaged fibers during the reducing size process.

With regard to chemical composition of bagasses, wood can be replaced by bagasses for nearly all purposes because of the similar chemical composition and structure of cell. Physical properties of boards have proved conclusively the sound competitive position of bagasses particleboard, compared even with high-quality particleboard produced from wood.

2.3 Polymer Foam [8]

Cellular plastics or plastic foams, also referred to expanded or spong plastics, generally consist of a minimum of two phases, a solid polymer matrix and a gaseous phase derived from a blowing agent. The gases that may be used for foaming may be derived from any of a number of sources: air may be whipped in to the liquid, as in the frothing of latexes; a gas such as carbon dioxide may be dissolved in the liquid, often under pressure, and may be brought out of solution for foaming by reducing the pressure or by heating the solution; a low boiling liquid such as pentane or a fluorocarbon may be dissolved in the polymer and then converted to a gas by heating or by reducing the pressure; or gas may be generated by a chemical reaction, such as the reaction

of an isocyanate with water, or the decomposition of azodicarbonamide. There may be more than one solid phase present, as in the case of a blend or alloy of polymers (generally heterogeneous).

Other solid phases may be present in the foams in the form of fillers, either fibrous or other shapes. The fillers may be of inorganic origin, of a material such as glass, ceramic, or metal, or polymeric in nature. Foams may be flexible or rigid, depending upon whether their glass transition temperature is below or above room temperature, which in turn depends upon their chemical composition, the degree of crystallinity, and the degree of cross-linking. Intermediate between flexible and rigid foams are semirigid or semiflexible foams. The cell geometry may be open-(tunnels between the cells), or closed-cell. Closed-cell foams are most suitable for thermal insulation and are generally rigid, while open-celled foams are best for car seating, furniture, bedding and acoustical insulation, among other uses, and are generally flexible.

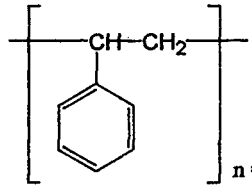
Plastic foams can be produced in a great variety of densities ranging from about 1.6 kg/m^3 to over 960 kg/m^3. Since the mechanical strength properties are generally proportional to the foam densities, the applications of these foams usually determine which range of foam densities should be produced. Thus, rigid foams for load-bearing applications require high density, fiber reinforcement, or both, while low densities are usually used for thermal insulation. Low-density flexible foams (around 30 kg/m^3) are usually used in furniture and automotive seating, while somewhat higher densities are used for carpet backing and energy-absorbing applications.

Figure 2.2 Schematic views of the gas structural elements of rigid phenolic foam : (a) open gas structural element; (b) closed gas structural elements [8]

Closed-cell structures are usually produced from polyurethane, epoxy resins, silicones, poly (vinyl chloride), polystyrene, etc., while open-cell materials are usually made from phenolic and carbamide (urea-formaldehyde,UF) foamed plastics.

2.3.1 Polystyrene Foam

Polystyrene is a clear, brittle, thermoplastic aromatic resin :



n = 1900 to 2900 (general-purpose resin)

It is one of the most versatile thermoplastic resins available for production of low cost plastic foams.

2.3.1.1 Preparation of Expansion Process

Foamed plastics can be prepared by various methods. The most widely used, called the dispersion process, involves dispersion of a gaseous phase throughout a fluid polymer phase, and the preservation of the resultant state. The expansion process has been the subject of extensive investigation because it is the foundation of foamed plastics. In general, the expansion process consists of three steps: creation of small discontinuities or plastic phase, growth of these cells to a desired volume, and stabilization of the resultant cellular structure by physical or chemical means.

2.3.1.2 Properties of Commercial Products

It is evident that polystyrene foams have a board range of physical properties (Table 2.4) the manufacturer should be consulted for the properties of a particular product.

Table 2.4 Physical properties of commercial foams [8]

Property	Polystyrene							
	ASTM test	Extruded plank		Expanded plank			Extruded sheet	
Density, kg/m^3		35	53	16	32	80	96	160
Mechanical properties								
Compressive strength, KPa at 10%	D1621	310	862	90-124	207-276	586-896	290	469
Tensile strength, KPa	D1623	517		145-193	310-379	1,020-1,186	2,070-3,450	4,137-6,900
Flexural strength, KPa	D790	1,138		193-241	379-517			
Shear strength, KPa	C273	241			241			
Thermal properties								
Thermal conductivity, W/(m.K)	C177	0.03		0.037	0.035	0.035	0.035	0.035
Electrical properties								
Dielectric constant	D1673	<1.05	<1.05	1.02	1.02	1.02	1.27	1.28
Dissipation factor		<0.0004	<0.0004	0.0007	0.0007	0.0007	0.00011	0.00014
Moisture resistant								
Water absorption, vol%	C272	0.02	0.05	1-4	1-4			
Moisture vapor transmission, g/(m.s.GPa)	E96	35		<120	35-120	23-35	86	56

About thermal properties; the thermal conductivity of cellular polymers has been thoroughly studied in heterogeneous material and plastic foams. Heat transfer can be separated into its component parts as follows:

$$\lambda = \lambda_s + \lambda_g + \lambda_r + \lambda_c \qquad (2.1)$$

where λ = total thermal conductivity, and λ_s, λ_g, λ_r, and λ_c represent solid conduction, gaseous conduction, radiation, and convection, respectively.

As a first approximation, the heat conduction of low-density foams through the solid and gas phases can be expressed as the product of the thermal conductivity of each phase and its volume fraction. Most rigid polymers have thermal conductivity of 0.07-0.28 W/(m.K), and the corresponding conduction through the solid phase of a 32 kg/m^3 foam (3 vol%) ranges from 0.003 to 0.009 W/(m.K). In most cellular polymers this value is determined primarily by the density and

the polymer-phase composition. Smaller variations result from changes in cell structure. Although conductivity through gases is intrinsically much lower than through solids, the amount of heat transferred through the gas–phase in a foam is usually the largest component of the total heat transfer because of the large gas phase volume (approximately 97 vol% in a 32 kg/m^3 foam). Ordinarily, convection cannot be detected in cells of diameter less than 4 mm. Since most cellular polymer have cell diameters under 4 mm, convection can be ignored. The variation in total thermal conductivity with density is similar for all cellular polymers (see Figure 2.3). The increase in λ at low densities is due to increased radiant heat transfer, at high densities to an increasing contribution of λ_s.

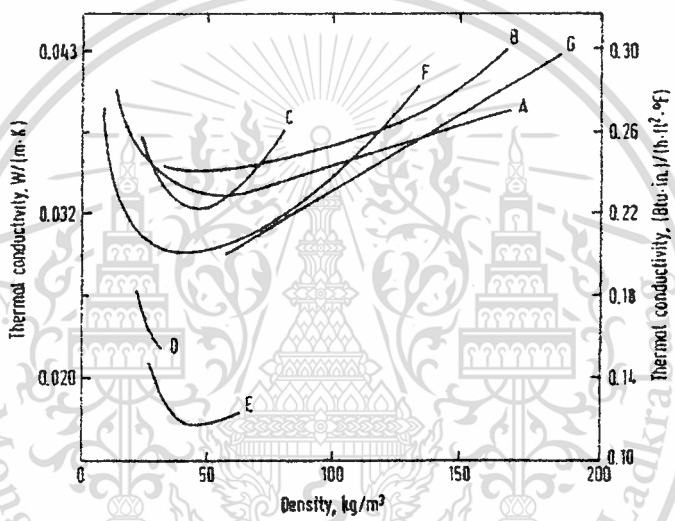


Figure 2.3 Effect of density on thermal conductivity of rigid cellular polymers [8-11].

A : polystyrene [9], B : polystyrene [10], C : polyurethane-air [10],

D : polyurethane-CFC 11 (CCl_3F) [11], E : polyurethane [10],

F : phenol-formaldehyde [10], G:ebonite [10]

Thermal conductivity of most materials decreases with temperature. When foam structure and gas composition are not influenced by temperature, the λ of the cellular material falls with decreasing temperature. When the composition of the gas phase changes, such as upon the condensation of a vapor, the relationship of λ to temperature is much more complex. The thermal conductivity of a cellular polymer can change upon aging under ambient conditions if the gas composition is influenced by aging. Thermal conductivity of foamed plastics varies with thickness. This has been attributed to the boundary effects of the radiant contribution to heat transfer.

The acoustic properties of polymers are altered in a cellular structure. Sound transmission changes only slightly, because it depends predominantly upon the barrier density, in this case the polymer phase. Therefore, cellular polymers by themselves are poor materials for reducing sound transmission. They are, however, effective in absorbing sound waves of certain frequencies. Materials with open cells on the surface are particularly effective in this respect. The combination of other advantageous physical properties with fair acoustical properties has led to the use of plastic foams in sound proofing.

2.3.1.3 Applications

The applications of polystyrene are a lot. Energy conservation and safety have stimulated growth in applications for insulation and cushioning in transport. A healthy economy is also expected to increase the demand for cushioning in furniture, bedding, and flooring, as well as for packaging. Structural foams are widely used as substitutes for wood, metal, or unfoamed plastics.

2.3.1.4 Expanded Polystyrene (EPS)

Due to polystyrene foam is a rigid plastic material with a wide range of densities and applications so there are five basic types of polystyrene commercial products that are expaned bead molding, extruded board, extruded sheet, injection-molded structural foam and expanded loose-fill packaging. This thesis focus on expaned bead molding only.

Expanded polystyrene (EPS) beadboard insulating is produced with expandable polystyrene beads. These beads are impregnated with 5-8% pentane and preexpanded by fabricators, with steam or vacuum. Then they are fed to steam-heated block molds, where expansion and fusion of beads continue. Block densities range from 13-48 kg/m^3, with 24 kg/m^3 most common for cushion packaging and 16 kg/m^3 for insulation.

Expanded polystyrene bead-molding products account for the main portion of the drinking cup market and are used in packaging materials, insulation board, and ice chests. The material cost is much lower.

2.4 Synthetics Binders [4,5,7,12,13]

Three major synthetic resins types are used in the board industry. By far the most dominant is urea-formaldehyde (UF), followed by phenol-formaldehyde (PF) and melamine-formaldehyde (MF). Another interesting but little used synthetic binder is polyisocyanate.

Urea and melamine resins are also know as amino resin and are the reaction products of amino and amido groups of aldehydes, most commonly, formaldehyde. The reaction causes formaldehyde to condense with the amino/amido compound to form methylol derivatives with upon further heating form the cured, colorless resin. These resin and phenol-formaldehyde resin can be cured rapidly in the presence of catalysts with the application of heat. As noted, the resins are build up by condensation polymerization.

Soluble and fusible (thermoplastic) intermediate products can be isolated during the production of the particular resin derived and these intermediates can be used to fabricate the final products. This is of great importance to the technology of this resins. Most of applications are based on the ability to use intermediate condensation products to generate adhesives suitable for manufacturing wood panels bonded together with high-molecular- weight condensation polymers. The intermediate products are fusible or thermoplastic low-molecular- weight polymers. To convert to infusible or thermosetting products, cross-links are built up between the low polymers giving a three-dimensional structure in the cured resin.

The amount of resin used is usually in the range 4% to 12% of dry wood. However this proportion may vary according to the type and size of wood fibers or particles. For example, in three layer particleboard, the coarser core material may contain 4% to 10% resin, while the finer surface layers may have 10% to 12% resin.

2.4.1 Urea-Formaldehyde Resin

Urea resins are the first choice of chipboard manufacturers for three main reasons: they are easy to use, they are cheap, and quality of the board is highly satisfactory for most current applications.

General Chemistry :

UF and MF polymerize in discrete addition (methylolation) steps and condensation steps (Figure 2.4) similar to the chemistry for PF. There are four reactive sites on a urea-formaldehyde molecule but only three sites may methylolate due to crowding.

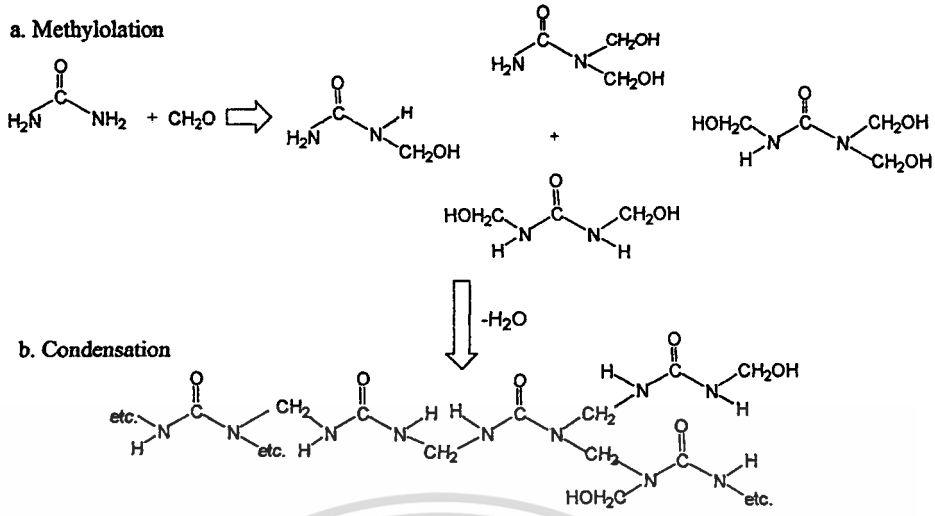


Figure 2.4 Reactions in the formation of UF resin [12]

Five important parameters largely determine the course and rate of the reaction and the properties of the resin. They are temperature and time of reaction, pH value, concentration of reactants, and the molar ratio of formaldehyde to urea. In the case of chipboard resins the formaldehyde/urea ratio has been gradually lowered over the year because it is one of the most effective ways of reducing the smell of formaldehyde. But decreasing the molar ratio cannot entirely eliminate formaldehyde fumes : the degree of reaction, type of hardener, length of curing time in relation to the hardener, and curing temperature all have an influence. More over, since formaldehyde is split off from the resin in the process of curing, the problem of completely eliminating its smell, either during manufacture of the board or subsequently, is a difficult one.

The natural concentration of the resin solution on completion of the production is 40-45%, and usually a quantity of water is evaporated (under vacuum at low temperatures) in order to increase the resin content to 65-70%. For spraying on to wood chips the chipboard manufacturer normally dilutes the resin to about 50% which gives a suitable viscosity for air-jet spraying; for airless spraying a higher viscosity is acceptable.

If a resin is required in powder form, the evaporation of water is carried almost to completion by spray-drying. In practice, however, the powder resin does not start life as precisely the same material as that for supply as a liquid.

At 65-70% concentration aqueous solution of UF resins are stable at 20 °C for several week, and at 50% for many month; as powder they have a shelf-life of one to two years. Properties

however change during storage: diluability with water, and pot-life on addition of a hardener gradually decrease, while the viscosity solid gradient becomes steeper.

Curing :

A UF resin is capable of curing to an infusible solid by means of heat alone; some formulae cure at room temperature, other require hot pressing at 210 °F (99 °C) to 250 °F (121°C), but curing is normally accelerated by adding either an acid or an acid generating substance-the hardener. The acid does not combine in the curing reaction, the effect being entirely the catalytic one of the hydrogen ion. If the wood chips are acidic (and softwood chips usually are) the addition of a hardener is not by any means essential, although in order to get a fast curing is usually desirable.

Properties :

Moderate durable under damp condition and moderate to low resistance to temperature excess 120 °F.

2.4.2 Phenol-Formaldehyde Resin

Phenolic resins have always cost more than urea resins. In addition, it takes somewhat longer for the resin to cure out in a given board as compared with urea resin. Catalytic systems have been developed recently that have significantly decreased the press time when using phenolic resins. Of more importance in comparison with urea resins at the present time is the previously mentioned shortage of the raw materials needed for producing phenolics. Many plants in the United States have had their phenolic resins allotted at about 65% of their normal use during periods of high demand.

General Chemistry :

Phenolic polymers are formed with a phenolic or phenol derivative monomer and formaldehyde crosslinking agent in two discrete steps. The first step, shown in Figure 2.5, is an addition or methylolation step. Formaldehyde reacts with an active *ortho* or *para* proton to form the addition product which is a methylolated phenolic. Mono-, di- and tri- methylol derivatives are possible.

The second step, shown in Figure 2.5, is a condensation step. Water is generated as a condensation byproduct and is formed with a methylolhydroxy and neighboring active proton. The combination of addition-condensation steps yields a polymer network, which is the backbone of the adhesive resin. The reaction steps leading to resin formation are generally performed at elevated temperature in a chemical reactor capable of heating, cooling, good agitation, vacuum distillation and atmospheric reflux.

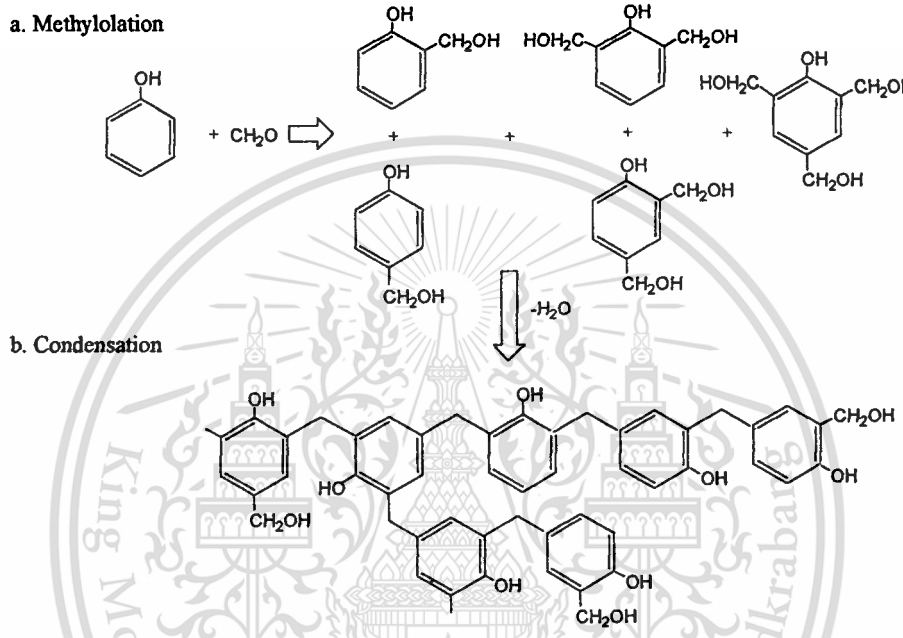


Figure 2.5 Reactions in the formation of PF resin [12]

Curing :

The phenolics are slower curing than the ureas. They are more heat stable and require higher press temperatures. Temperatures in the range of 250 to 300 °F (127-149 °C) in the core are needed. Platens range up to over 400 °F (204 °C) in temperature. Catalysts to speed pressing time, such as resorcinol, can be used but this particular catalyst is quite expensive. The final cured resin is heat and chemical resistant.

Properties :

Phenolic resins for bonding are fairly high in molecular weight. They stay in the particle surfaces and develop durable, rigid , strong waterproof bonds between the particles. Another type of the phenolic resin is of interest to bond manufacturers: aqueous solutions of low molecular

weight. These resins have the ability to penetrate and swell the cell walls of the wood. When cured under heat, these resins strengthen the wood and impart excellent dimensional stability.

2.5 Wood Composites Adhesion Mechanisms [12,14]

The properties of composites made from wood components are also influenced by wood particle size, geometry and manufacturing process variables. The challenges and opportunities for wood bonding are derived by the nature of the interaction of the substrate with the resin.

The actual bonding between the adhesive polymers and the wood polymers is attributed to a combination of three mechanisms.

The relative importance of these three mechanisms are still the subject of debate among adhesive chemicals.

1). Mechanical Interlocking : Adhesive polymer and porous wood fibers invariably intertwine both microscopically and molecularly to form mechanical interlocks. Bonding strong from this mechanism depends upon spreads, penetrates, molecular weight of adhesive and wets a wood surface. Penetration of adhesive two to six fibers deep into the wood and fiber walls on a molecular scale is generally thought to be necessary for durable structural bond.

2). Intermolecular Physical Attraction : Physical attraction between wood and adhesive polymers can occur from Van der Waals forces and hydrogen bonds. This physical absorption (specific adhesion) can be quite strong, especially the H-bonds between polar hydroxy groups on fiber-wall carbohydrates and adhesion polymer.

3). Chemical Bonding : Covalent chemical bonds between wood fiber and adhesion though the sharing of electrons is probable in cross-linking adhesive systems, which is the highest bond strong than other mechanisms. However, the presence of such bonds may not be essential to waterproof adhesive bonds. Intermolecular physical attractions are sufficient for waterproof adhesive bonds.

2.6 Acoustical Properties [15-20]

Excessive noise can have a lasting adverse affect upon health, lower efficiency at work and is considered by many people as diminishing their quality of life. In order to establish sound absorption materials, some common terms which concerning to acoustic properties should be know.

2.6.1 Nature of Sound

Sound is caused by fluctuations in air pressure. These fluctuations start from the source of the sound, which may be a plucked string, a not too well-balanced motor, or simple a crying baby, where the source of the fluctuations are the vibrating vocal cords.

Whatever the intensity of the sound, its speed of transmission depends upon the modulus of elasticity and the density of the medium through which it passes. The velocity of sound is quoted as:

$$v = k\,(E/D)^{1/2} \tag{2.2}$$

where V is the velocity of sound in m/s, E is the modulus of elasticity of the medium in the Pascals, D is the density of the medium in kg/m^3, and k is a constant equal to 0.843 (dl).

The vibration of a drumhead or a guitar body pushes against the air to produce pressure waves that propagate to our ears and are perceived as sound. The response of human ears is limited to a range of frequencies from about 20 Hz to about 20,000 Hz. In general, as we grow older the upper limit of audible frequencies drops. It is not uncommon to find people with adequate hearing whose range of audible frequencies extends to only 10,000 0r 15,000 Hz. Those frequencies between 20 Hz and 20,000 Hz are usually referred to as *audio*, or *sonic*, frequencies. Vibrational frequencies above 20,000 Hz are beyond our hearing and are referred to as *ultrasonic* frequencies. Similarly, extremely low frequencies are called *infrasonic* frequencies. Ultrasonic vibrations generate soundlike waves, but we do not hear them because of the limitations of our ears. It is well known that many animals, including dogs, can hear frequencies well above those audible to people.

2.6.2 Sound Pressure Level

The sound pressure actually experienced at any position relative to the source of the sound is given in pascals or the intensity of sound pressure level actually received by the observer. Again, due to the wide range of pressures actually experienced a decibel is used, based this time upon a sound pressure of $2x10^{-5}$ Pascals.

The sound pressure level is defined by the equation:

$$\text{Number of dB sound pressure level} = 20 \log \frac{\text{sound pressure level in pascals}}{2x10^{-5}\ \text{Pascals}} \tag{2.3}$$

For example, the maximum level of noise in a boilermaker's workshop can be measured to be about 20 Pascals. This would be equal to 120 dB.

2.6.3 Sound Absorption

How Sound is Absorbed

Basically, sound energy is 'absorbed' when it is converted to another form of energy. In most cases, this takes the form of conversion to heat. This results from the actions of friction and the resistance of various materials to movement and deformation. Obviously the amount of heat generated is minimal as the sound energy is also quite small if you consider it in Watts.

In actual material media the geometrical attenuation is supplemented by absorption due to the interaction between the sound wave and the physical properties of medium. This dissipates the sound energy by transforming it into heat and hence decreases the intensity of the wave.

Porous Absorbers

Porous absorbers are the most familiar and commonly available kind. They include fibrous vegetable or mineral materials, foams, fabrics, carpets, soft plasters, acoustical tile, and so on. Many books said likely about sound absorption mechanism. Doug Jones and Jeff Szymanski [18] said that the sound wave causes the air particles to vibrate down in the depths of porous materials, and frictional losses convert some of the sound energy to heat energy. The amount of loss is a function of the density or how tightly packed the fibers are. If the fibers are loosely packed, there is little frictional loss. If the fibers are compressed into a dense board, there is little penetration and more reflection from the surface, resulting in less absorption.

Andrew March [16] said that conversion to heat is produced by friction when vibrating air molecules are forced through the pores and interact with the pore walls. A.Komar [19] said that the character of sound absorption of porous materials with a solid skeleton is absorbed as a result of viscous friction inside the pores, so that the sound energy transforms into heat (foamed glass, gas concrete and other porous materials with a solid skeleton). In case of porous materials with a flexible skeleton, there appear viscous friction in the pores and relaxation losses due to the deformation of the non-rigid skeleton (mineral, glass, basalt and cotton wool, wood-fiber boards and other materials of similar characteristics). In case of panel materials and constructions whose sound absorption is due to an active resistance of the system which effects forced vibrations under

the action of an incident wave (thin veneer panels, rigid wood-fiber boards, soundproof cloths and others).

The sound absorption defined in absorption coefficient α which depends upon the nature of the material and also upon the frequency of the sound concerned. In general, sound absorption are higher for high frequency sounds than for low frequency ones.

Absorption Coefficient

When sound waves strike a surface, a fraction of the incident energy is absorbed and a fraction is reflected. The sound absorption coefficient of a surface is the ratio of energy absorbed by the surface is the ratio of is energy absorbed by the surface to the energy incident on the surface. At a given frequency, the absorption coefficient is a function of angle of incidence. For acoustic designing in architecture it is convenient to use an average absorption coefficient a, which represents an average over all angles of incidence, and which is assumed to depend only on the physical characteristics of the material and not on the sound field. These are the values of the coefficient that are given in this article.

The average value of the sound absorption coefficient of a material varies with frequency which usually list values of a at 125, 250, 500, 1000, 2000 and 4000 Hz. In general, absorptivities are higher for high frequency sounds than for low frequency ones.

In comparing materials that are used for noise reduction purposes in office, banks, corridors and so forth, a single figure called the noise reduction coefficient (NRC) is sometimes used. It is the average of the absorption coefficient at 250, 500, 1000, and 2000 Hz, to the nearest multiple of 0.05. Values of absorption coefficient for various types of building materials are given in Table 2.5.

Table 2.5 Absorption coefficients of general building materials [20]

Material	Values of α					
	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Brick, unglazed	0.03	0.03	0.03	0.04	0.05	0.07
Carpet, heavy						
- On concrete	0.02	0.06	0.14	0.37	0.60	0.65
- On 40-oz/yd^2 (1.36 kg/m^2) hair-felt or foam rubber	0.08	0.24	0.15	0.69	0.71	0.73
Concrete block						
- Coarse	0.36	0.44	0.31	0.29	0.39	0.25
- Painted	0.10	0.05	0.06	0.07	0.09	0.08
Fabrics						
- Light velour, 10-oz/yd^2 (0.34 kg/m^2), hung straight, in contact with wall	0.03	0.04	0.11	0.17	0.24	0.35
- Heavy velour, 18-oz/yd^2 (0.61 kg/m^2), draped to half area	0.14	0.35	0.55	0.72	0.70	0.65
Floorings						
- Concrete or terrazzo	0.01	0.01	0.02	0.02	0.02	0.02
- Linoleum, asphalt, rubber, or cork tile on concrete	0.02	0.03	0.03	0.03	0.03	0.02
- Wood	0.15	0.11	0.10	0.07	0.06	0.07
Glass						
- Large panes of heavy plate glass	0.18	0.06	0.04	0.03	0.02	0.02
- Ordinary window glass	0.35	0.25	0.18	0.12	0.07	0.04
Gypsum board 1/2 in. (12.7 mm) nailed to 2 X 4's 16 in (406 mm) on center	0.29	0.10	0.05	0.04	0.07	0.09
Marble or glazed tile	0.01	0.01	0.01	0.01	0.02	0.02
Plaster, gypsum or lime						
- Smooth finish on tile or brick	0.01	0.01	0.02	0.03	0.04	0.05
- Rough finish on lath	0.14	0.10	0.06	0.05	0.04	0.03
Plywood paneling , 3/8 in. (9.5 mm) thick	0.28	0.22	0.17	0.09	0.10	0.11

2.7 Thermal Properties [19,21]

Building practice is mostly concerned with the protection against heat and cold. Thermal insulating can thus be considered as means of slowing down energy loss or, to express it in another way, of reducing the rate of entropy increase. Put more simply, thermal insulating is intended to keep cold areas and media cold, and hot areas and media hot. It does this by the preventing of heat transfer.

2.7.1 Modes of Heat Transfer

All modes of heat transfer require the existence of a temperature difference, and are from the high-temperature medium to a lower-temperature one.

1. Conduction Conduction is the transfer of energy from the more energetic particles of a substance to the adjacent less energetic ones as a result of interactions between the particles. Conduction can take place in solids, liquids, or gases. In gases and liquids, conduction is due to the collisions of the molecules during their random motion. In solid, it is due to the combination of vibrations of a molecule in a lattice and the energy transport by free electrons.

Thermal conductivity, λ is defined as the heat flow in watts (joules/second) which takes place across a cube 1 meter^2 in cross-section and 1 meter in thickness, if the difference in temperature between the two faces is 1 °C. Its dimensions are therefore watts/meter °C or W/m.K.

2. Convection Convection is the mode of energy transfer between a solid surface and the adjacent liquid or gas that is in motion, and it involves the combined effects of *conduction and fluid motion*. The faster the fluid motion, the greater the convection heat transfer. In the absence of any bulk fluid motion, heat transfer between a solid surface and the adjacent fluid is by pure conduction. The presence o bulk motion of the fluid enhances the heat transfer between the solid surface and the fluid, but it also complicates the determination of heat transfer rates.

3. Radiation Radiation is the energy emitted by matter in the form of electromagnetic waves (or photons) as a result of the changes in the electronic configurations of the atoms or molecules. Unlike conduction and convection, the transfer of energy by radiation does not require the presence of an intervening medium. In fact, energy transfer by radiation is faster (at the speed of light) and it suffers no attenuation in a vacuum. This is exactly how the energy of the sun reaches the earth.

2.7.2 Thermal Insulating Materials

Thermal insulating properties of material are governed not only by their porosity, but also by the nature of pores, their distribution, size and whether they are open or close. Highest in thermal insulating properties are materials with a greater number of fine, closed and air-filled pores. Air, when immobile, has a very low coefficient of thermal conductivity (0.02423 W/m K at 0 °C and 0.03185 W/m K at 100 °C [15]). If the structure of highly porous material with fine and closed pores is studied with a microscope, a host of air cells separated by thin walls becomes readily apparent. The totality of such cell a serves as a barrier in the way of heat transfer, and thus makes

the material as a whole poorly thermal conducting. Thermal insulating properties of material may be improved by increasing the number of air cells and arranging the separating walls in a honeycomb pattern.

Thermal insulating properties of air are greater when it is still, since air motion favours heat transfer. In materials of cavernous structure with large and elongated pores convection air streams arise more easily, thus increasing heat transfer through the material. The finer the pores, or the smaller the volume of air enclosed inside them, the lower is its mobility and the better are its thermal insulating properties.

Thermal insulating properties of material depend upon the ratio of the volume of air enclosed in the air cells, to the volume of solid matter per unit volume of the materials. The thinner of solid matter, surrounding the air cell, the better are the thermal insulating properties of material and the lower is its coefficient of thermal conductivity. In very porous materials of a very low bulk density, the volume of air enclosed inside the pores is so large and the thermal insulating properties are so high that the part of the solid matter engaged in heat transfer becomes negligible. In these materials, the coefficient of thermal conductivity approximates that of air.

When we compare thermal conductivities of materials of a same composition, but of different porosities, it becomes evident that coefficient of a thermal conductivity is almost proportional to the bulk density of material, i.e., to its solid matter content.

Pores and channels in material may be formed by foaming, by introducing gas forming agents, by contact gluing or fritting of separate grains or particles, by random laying of a great number of fibers, etc.

Thermal insulating properties of material are greatly affected by its structure, this being particularly evident in fibrous materials. For example, thermal conductivity of wood along the fibers is about twice as great as that across the fibers. Thermal insulating properties of powder material are greatly affected by the size of grains: they improve with the reduction in size of grains even when the bulk density remains constant.

By considering the general nature of thermal insulating materials we come to the conclusion that their low thermal conductivity is due to air filled pores; when the surface of these pores is covered with a film of water or the pores are filled with water, the thermal insulating properties of material greatly decrease, because water has a much higher (about 25 times) coefficient of thermal conductivity than air. Therefore, thermal insulating materials should be protected against moistening.

2.8 Literature Reviews

Puranan A. and Udomsak P. [22] studied on preparation of particleboard from mixed bagasse fiber waste and polystyrene foam in various ratios. Poly(vinyl acetate) and urea-formaldehyde were used as adhesives amount of 20 and 30 g. Two ratios of urea-formaldehyde:water were prepared 1.5 : 1 and 1 : 1 by weight. It was found that physical, mechanical and sound absorption properties were increased with increasing bagasse fiber. Density, physical properties and sound absorption increased with increasing ratio of urea-formaldehyde but moisture content decreased. Increment of foam enhanced sound absorption property. Comparing two types of adhesives, urea-formaldehyde provided better properties than poly(vinyl acetate).

Sirinun W. and Supansa O. [23] studied on manufacturing of fiberboard which was prepared by mixing bagasse fiber with polystyrene foam which was used as impact material. Polystyrene foam was cut into 2-4 mm and 4-6.48 mm. Urea-formaldehyde, poly(vinyl acetate) and dextrin were used as adhesives. Ratio of polystyrene foam to bagasse fiber to adhesive is 8:30:40 by weight. It was found that urea-formaldehyde and poly(vinyl acetate) provided strength to fiberboards better than detrin. Polystyrene size of 4-6.48 mm showed better sound absorbent property when compared with glass fiber-reinforced ceiling board. Mechanical properties of these fiberboards were lower than commercial glass fiber-reinforced ceiling board. Among three kinds of adhesives, urea-formaldehyde gave the highest mechanical and sound absorbent properties.

Sarocha Charoenvai and Jongjt Hirunlabh [3] developed the new insulating particleboards from durian peel and coconut coir with low thermal conductivity as a component of construction panels for energy conservation of building. Two main parameters were investigated namely binding types (UF 12%, PF 6%, and IC 3%) and board density. In general, the effect of adhesive types on the properties of boards was not obvious whereas that of the density was more significant on most properties of boards.

Experimental investigation indicated that the mechanical strength of all boards such as modulus of rupture and modulus of elasticity increased with increasing board density, but it is still rather low. However, this decreased the dimensional stability, measured in term of thickness swelling, and thermal conductivity as well.

Finally, as the raw materials are agricultural waste, manufacturing particleboards is therefore an economic and interesting option. Such natural particleboards with a low thermal conductivity could be utilized for specific applications as insulating ceiling and walls.

Xiaoqun M. et al [24] characterized the physical properties of medium density wheat straw particleboard as affected by various types of adhesives, including methylene diphenyl diisocyanate (MDI), urea formaldehyde (UF), soybean protein isolate (SPI), and soybean flour (SF), as well as chemical treatment of straw. Wheat straw particleboard was molded using a hot press. Mechanical properties, water absorption, thickness swelling, and equilibrium moisture content were measured on the resulting particleboard. Among all adhesives, particleboard made from MDI showed superior mechanical performance and water resistance. Particleboard made from bleached straw had improved mechanical performance over that made from untreated straw. Soybean-based adhesives showed similar or better mechanical strength than UF resins for particleboard made from bleached straw, which indicated that soybean-based adhesives could be used to replace UF resin for indoor construction and furniture to avoid toxic emission from UF. Although the soybean-based adhesive had poorer mechanical properties than MDI resin, it is environmental friendly and could be used in applications with less stringent requirements for mechanical strength.

Han-Seung Y. et al [25] characterized the physical properties of rice straw-wood particle composite for sound absorbing wooden construction material. The manufacturing parameters were: a specific gravity of 0.4, 0.6 and 0.8 and a rice straw content (10/90, 20/80 and 30/70 weight of rice straw/wood particle) of 10,20 and 30 wt%. A commercial urea-formaldehyde adhesive was used as the composite binder, to achieve 140-290 psi of bending modulus of rupture (MOR) with 0.4 specific gravity, 700-900 psi of bending MOR with 0.6 specific gravity and 1400-2900 psi of bending MOR with a 0.8 specific gravity. All of the composite boards were superior to insulation board in strength. Width and length of the rice straw particle did not affect the bending MOR. The composite boards made from a random cutting of rice straw and wood particles were the best and recommended for manufacturing processes. Sound absorption coefficients of the 0.4 and 0.6 specific gravity boards were higher than the other wood-based materials. The recommended properties of the rice straw-wood particle composite boards are described, to absorb noises, preserve the temperature of indoor living spaces, and to be able to partially or completely substitute for wood particleboard and insulation board in wooden constructions.

Terry Sellers et al [26] characterized the physical properties of lignocellulosic-based composites made of kenaf core. Three synthetic resins were used to bond the kenaf core (<6.3 mm size) into flat panels, approximately 25 mm thick. The resins were urea-formaldehyde,

phenol-formaldehyde and polymeric diphenylmethane diisocyanate, applied at 8%, 4% and 3% resin solids, respectively. The panels were hot-press cured, resulting in a panel density of 240 kg m^{-3}. Typical physical properties of the kenaf core panels across resin types were internal bond 195 kPa, modulus of rupture 756 kPa, modulus of elasticity 117 MPA and compression (parallel) 983 kPa. Thickness swell after 2 and 24 hours water soaking were 12% and 15% respectively. Nail withdrawals of kenaf panels were similar to nail withdrawals of medium density fiberboard used as siding and about 50 to 60% of structural softwood plywood and oriented stradboard. Screw holding capacity of kenaf panels was about 8% of medium-density wood and wood-based but about 50% of low-density particleboard (<640 kg m^{-3}). The thermal transmission properties of the kenaf core panels (R>2) were twice as efficient as plywood and about one-haft as glass wool insulation. The acoustic properties of 25-mm kenaf core panels were equal to 16-mm modulated soft texture tile at the low frequency levels (125-1000 Hz) and 50% better at the higher frequencies (2000 and 4000 Hz). The kenaf core panels were substantially better than 13-m gypsum board in acoustic properties. In essence, kenaf core panels would make excellent ceiling tiles, decorative panel substrates, floor tile substrates and certain structural components.

CHAPTER 3

METHODOLOGY OF EXPERIMENT

3.1 Raw Materials

1. Bagasses (BG) from *The Cholburi Sugar Corporation Ltd.* were classified into 2 sizes.

   1.1 BG of 20-35 mesh (grinded and screened)

   1.2 BG of less than 20 mesh (screened only)

Sizes	BG of 20-35 mesh [1]	BG of less than 20 mesh [2]
average width (mm)	0.565	3.915
average length (mm)	2.461	45.614
aspect ratio [3]	4.356	11.651

Remark : [1] Their sizes obtained by measuring 50 pieces of BG of 20-35 mesh through SEM micrographs.
[2] Their sizes obtained by measuring 50 pieces of the actual pieces of BG of less than 20 mesh.
[3] Aspect ratio was calculated from average length divided by average width.

2. Expanded polystyrene foam (EPS) from packaging and cushioning was gathering, grinding and screening into 3 groups.

   2.1 EPS diameter of 2-3 mm

   2.2 EPS mixed size : Compost of diameter of less than 2 mm 25%, diameter of 2-3 mm 35%, diameter of 3-6 mm 39% and diameter of more than 6 mm 1%

   2.3 EPS diameter of 3-6 mm

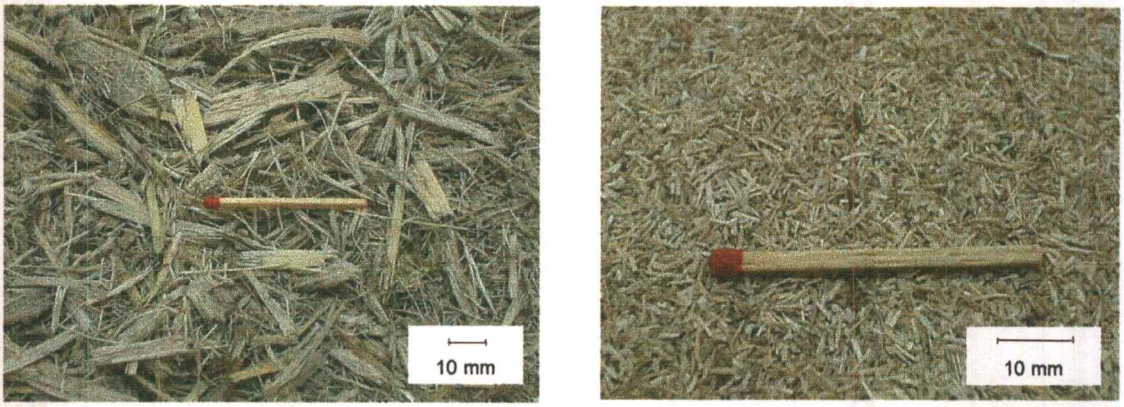
3. Urea-formaldehyde resin (UF)

Appearance	Light brownish powder
Trade name	Weldwood®
Product of	DAP INCORPORATION ; USA

4. Phenol-formaldehyde resin (PF)

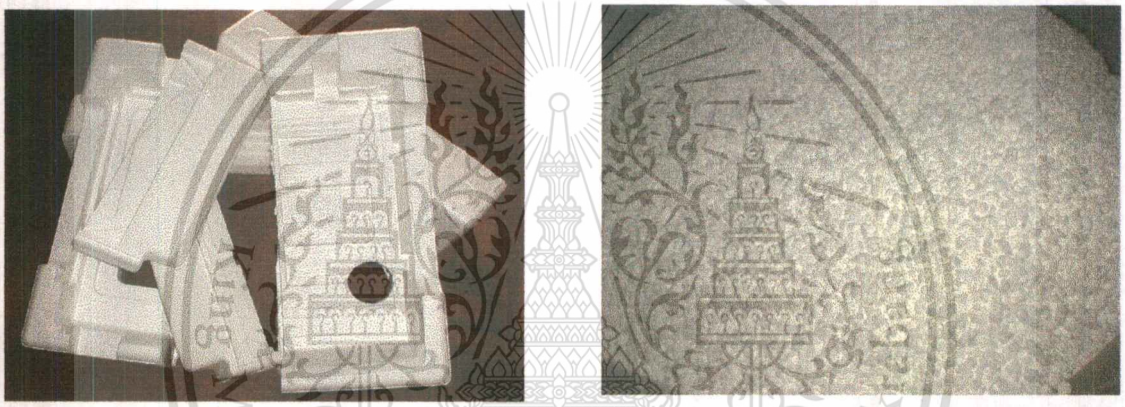
Appearance	Reddish liquid
%Solid content (105 °C x 3 hrs.)	45.23
Specific gravity (25 °C)	1.204
pH	13.81
Viscosity (25 °C;Brookfield, cps)	97
Product of	TOA-DOVECHEM INDUSTRIES CO.,LTD.

5. Distilled water



(a) (b)

Figure 3.1 Bagasses : (a) raw bagasses from sugar cane mill, (b) after grinding



(a) (b)

Figure 3.2 Expanded polystyrene foam : (a) before grinding, (b) after grinding

3.2 Apparatus for Particleboard Process

3.2.1 For Particleboard Process

1. Grinding machine : Hammer mill type of Bosco Engineering Co.,Ltd.
2. Sieve machine : Vibration type of RETSCH®
3. Paddle-type blender : Heavy duty drill press, model SE-330B of REXON®
4. Compression machine : Model 20 x 20 x 7, No. 27-1-92 of Chaijaroern Karnchang Factory, Bangkok
5. Blending container
6. Mat forming apparatus : Composted of steel caul sheets (46 cm x 46 cm x 0.3 cm), forming frame (30 cm x 30 cm x 0.9 cm) and forming box (30 cm x 30 cm x 30 cm)

3.2.2 For Specimen Testing

1. Sound level meter : Model NL-14 of RION®, Japan
2. Sound testing room (1 m x 1 m x 2 m)
3. Universal testing machine : LR 5K of LLOYD Instruments®
4. Oven : Model UM 400 of MEMERT®
5. Balance : Model TP-6101 of Denver Instrument Company
6. Micrometer
7. Thermal conductivity apparatus

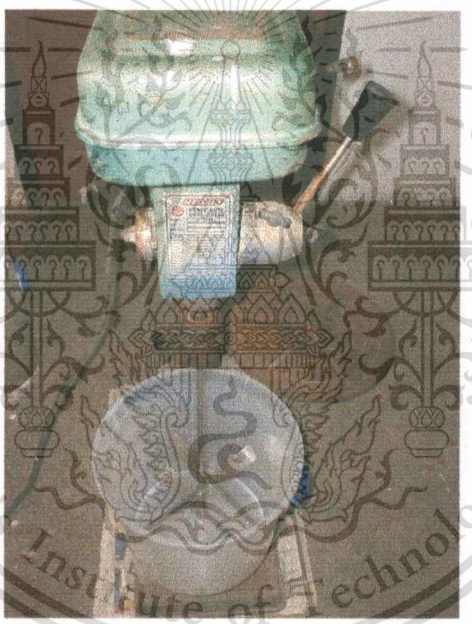
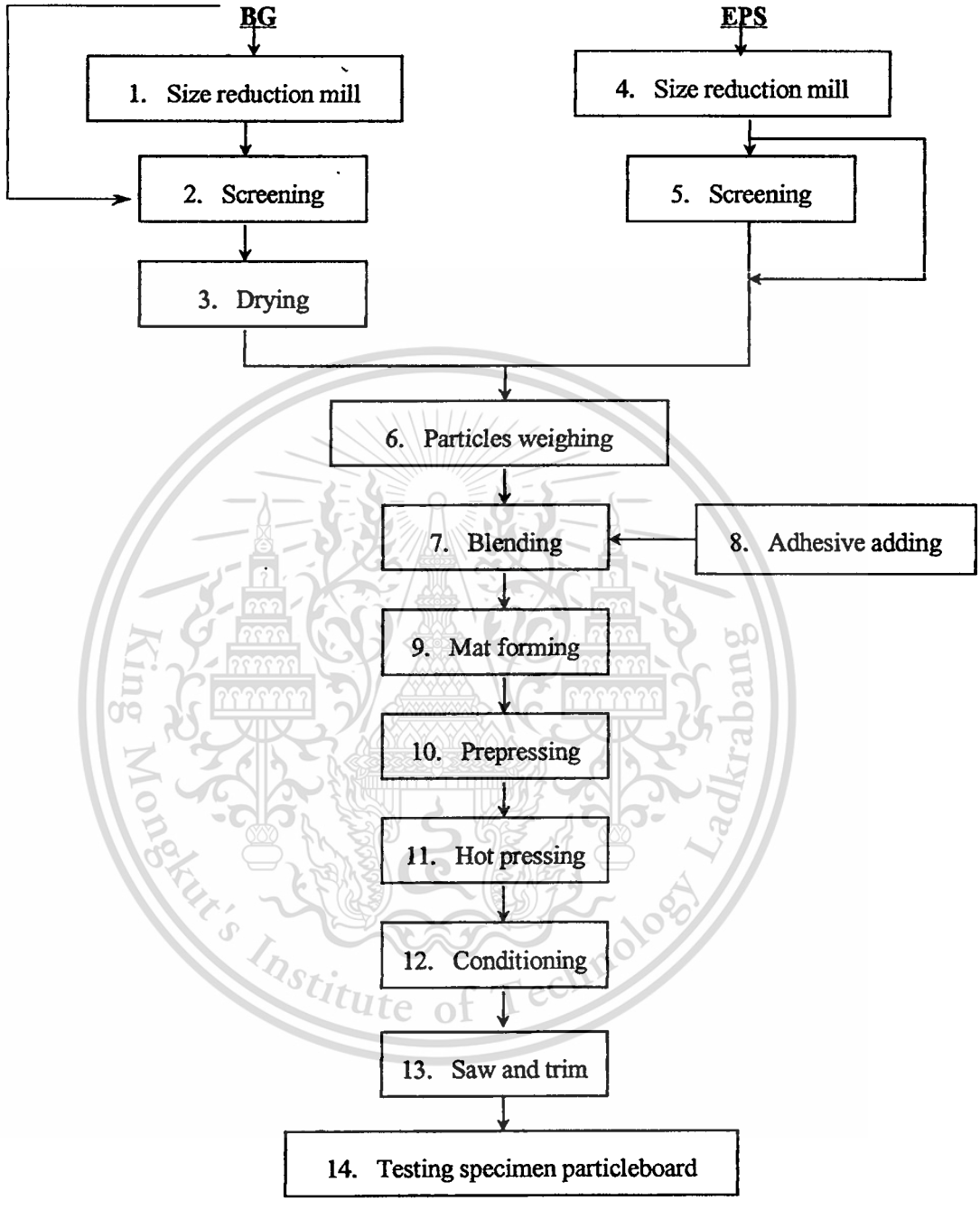


Figure 3.3 Paddle-type blender

Figure 3.4 Compression machine

Figure 3.5 Illustrate particles in mat forming apparatus

3.3 Process of Preparation Particleboard



The details are shown as below.

1. Size reduction mill : BG were milled one time by grinding machine. In case of BG of less than 20 mesh, this step was neglected.

2. Screening : In case of BG of 20-35 mesh, milled BG were screened by upper sieve with opening size of 0.841 mm (20 mesh) and lower sieve with opening size of 0.42 mm (35 mesh). In

case of BG of less than 20 mesh, milled BG were screened by upper sieve with opening size of 0.841 mm (20 mesh) only.

3. Drying : Screened BG were dried at 103 °C for 24 hrs or until their moisture content remain in the range of 3-6%.

4. Size reduction mill : EPS were milled one time by grinding machine.

5. Screening : In case of EPS diameter of 2-3 mm, milled EPS were screened by upper sieve with opening size of 3 mm and lower sieve with opening size of 1.68 mm. In case of EPS diameter of 3-6 mm, milled EPS were screened by upper sieve with opening size of 6 mm and lower sieve with opening size of 3 mm. In case of EPS mixed size, this step was neglected.

6. Particles weighing : Such BG and EPS were weighed follow calculated formulae.

7. & 8. Blending & Adhesive adding : Both BG and EPS were blended by *Paddle-type blender* as shown in Figure 3.3. And then adhesive was gradually added into the particles. Adhesive urea-formaldehyde was prepared in liquid form by dissolving with distilled water, UF/Water 60/40 by weight. On the other hand, phenol- formaldehyde used as received.

9. Mat forming : Mixture was poured in the forming box which place over the forming frame (mold). Then it was compressed in forming box by hand. Next, forming box was left out. Finally, the formed mat was covered by upper steel caul sheet and transferred to the prepressing.

10. Prepressing : The formed mat was consolidated into rigid cake with cold press by compression machine in order to reduce their thickness. Since the volume of the formed mat was larger than the volume of mold. Thus only one time of pressing was not enough to reduce their thickness. More one time of pressing was enough. And to ensure this process, more one time of pressing again was proceeded. So total of pressing was three times.

11. Hot pressing : The mat was pressed at 100 °C by compression machine as Tg of polystyrene is limited at around 100 °C. The pressing period were studied in this thesis. Then the hot boards were removed from the press. Finally, forming frame and steel caul steets were left out.

12. Conditioning : The boards were conditioned in a conditioning room for 1 week at room temperature in order to completely cure.

13. Saw and trim : The boards were sawed and trimmed into specific dimension for further testing.

14. Testing specimen particleboard : The specimens were measured sound absorption, thermal conductivity including mechanical and physical properties.

3.4 Study on Preparation Parameter Conditions

Particleboards preparation in this thesis were divided into 8 steps. Many parameters such as the amount of adhesives, ratios of BG/EPS, EPS sizes, curing times, board densities, etc. were selected from the suitable mechanical properties of tested composites.

3.4.1 Study on Adhesive Quantities for Good Board Appearance

This step aimed to find the suitable adhesive quantity which providing nonslip-loosed edges finishing boards. Because this area had weakest bond strength. Various percentages of adhesives were 6, 9, 12, 15, 20, 25 and 30% of dry particle weight (BG including EPS) as shown in Table 3.1 and 3.2. The suitable quantity was chosen after testing finishing board samples1-14.

Table 3.1 Summary of samples 1-7 used UF adhesive.

Items	Samples						
	1	2	3	4	5	6	7
BG/EPS ratio (wt/wt) BG (20-35 mesh)/EPS (2-3 mm)	90/10	90/10	90/10	90/10	90/10	90/10	90/10
Adhesive %UF (of dry particle weight)	6	9	12	15	20	25	30
Target density (g/cm^3)	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Hot pressing time (mins, at 100 °C)	5	5	5	5	5	5	5

Table 3.2 Summary of samples 8-14 used PF adhesive.

Items	Samples						
	8	9	10	11	12	13	14
BG/EPS ratio (wt/wt) BG (20-35 mesh)/EPS (2-3 mm)	90/10	90/10	90/10	90/10	90/10	90/10	90/10
Adhesive %PF (of dry particle weight)	6	9	12	15	20	25	30
Target density (g/cm^3)	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Hot pressing time (mins, at 100 °C)	5	5	5	5	5	5	5

3.4.2 Study on Ratios of BG to EPS

Based on the results of previous step, 15% of UF and PF of dry particle weight were chosen for studying. Three ratios of BG/EPS 95/5, 90/10 and 85/15 wt/wt were used. (Table 3.3)

Table 3.3 Summary of samples 15-20 based on various ratios of BG/EPS.

Items	Samples					
	15	16	17	18	19	20
BG/EPS ratios (wt/wt)						
BG (20-35 mesh)/EPS (2-3 mm)	95/5	90/10	85/15	95/5	90/10	85/15
Adhesives						
%UF (of dry particle weight)	15	15	15	-	-	-
%PF (of dry particle weight)	-	-	-	15	15	15
Target density (g/cm^3)	0.6	0.6	0.6	0.6	0.6	0.6
Hot pressing time (mins, at 100 °C)	10	10	10	10	10	10

3.4.3 Study on EPS Sizes

15% of UF and PF of dry particle weight and BG/EPS ratio at 85/15 wt/wt were chosen for studying the suitable EPS size. Three EPS diameters of 2-3 mm, mixed size and diameters of 3-6 mm were studied as shown in Table 3.4.

Table 3.4 Summary of samples based on selected EPS sizes.

Items	Samples					
	17	21	22	20	23	24
BG/EPS ratio (wt/wt)						
BG (20-35 mesh)/EPS (2-3 mm)	85/15	-	-	85/15	-	-
BG (20-35 mesh)/EPS (mixed size)	-	85/15	-	-	85/15	-
BG (20-35 mesh)/EPS (3-6 mm)	-	-	85/15	-	-	85/15
Adhesives						
%UF (of dry particle weight)	15	15	15	-	-	-
%PF (of dry particle weight)	-	-	-	15	15	15
Target density (g/cm^3)	0.6	0.6	0.6	0.6	0.6	0.6
Hot pressing time (mins, at 100 °C)	10	10	10	10	10	10

3.4.4 Study on Curing Times

The suitable parameter conditions received from 3.4.1-3.4.3 were used for studying curing time. 15% of UF and PF of dry particle weight, BG/EPS ratio at 85/15 wt/wt and mixed EPS size were chosen. Three curing times were varied in the range of 5, 10 and 15 minutes (Table 3.5).

Table 3.5 Summary of samples based on curing times.

Items	Samples					
	25	21	26	27	23	28
BG/EPS ratio (wt/wt)						
BG (20-35 mesh)/EPS (mixed size)	85/15	85/15	85/15	85/15	85/15	85/15
Adhesives						
%UF (of dry particle weight)	15	15	15	-	-	-
%PF (of dry particle weight)	-	-	-	15	15	15
Target density (g/cm^3)	0.6	0.6	0.6	0.6	0.6	0.6
Hot pressing times (mins, at 100 °C)	5	10	15	5	10	15

3.4.5 Study on Adhesive Quantities

From the first to fourth step, 15% of UF and PF of dry particle weight, BG/EPS ratio at 85/15 wt/wt, mixed EPS size and 10 minutes curing time were chosen for preparation particleboards. The amount of two kinds of adhesives were varied at 7 and 11% of dry particle weight. The test properties were compared with 15% of dry particle weight from 3.4.1 (Table 3.6).

Table 3.6 Summary of samples based on the amount of adhesives.

Items	Samples					
	29	30	21	31	32	23
BG/EPS ratio (wt/wt)						
BG (20-35 mesh)/EPS (mixed size)	85/15	85/15	85/15	85/15	85/15	85/15
Adhesives						
%UF (of dry particle weight)	7	11	15	-	-	-
%PF (of dry particle weight)	-	-	-	7	11	15
Target density (g/cm^3)	0.6	0.6	0.6	0.6	0.6	0.6
Hot pressing time (mins, at 100 °C)	10	10	10	10	10	10

3.4.6 Study on Board Densities

Particleboards which had densities of 0.1, 0.3 and 0.6 g/cm^3 were prepared by using 15% of UF and PF of dry particle weight, BG/EPS ratio at 85/15 wt/wt, mixed EPS size and 10 minutes curing time as shown in Table 3.7.

Table 3.7 Summary of samples at different densities.

Items	Samples					
	33	34	21	35	36	23
BG/EPS ratio (wt/wt)						
BG (20-35 mesh)/EPS (mixed size)	85/15	85/15	85/15	85/15	85/15	85/15
Adhesives						
%UF (of dry particle weight)	15	15	15	-	-	-
%PF (of dry particle weight)	-	-	-	15	15	15
Target densities (g/cm^3)	0.1	0.3	0.6	0.1	0.3	0.6
Hot pressing time (mins, at 100 °C)	10	10	10	10	10	10

3.4.7 Study on the Effect of Presence and Absence of EPS

To investigate the effects of EPS, particleboards at 0.3 and 0.6 g/cm^3 densities were prepared from the samples as shown in Table 3.8. The effects of presence and absence of EPS in the particleboards were compared.

Table 3.8 Summary of samples presence and absence of EPS.

Items	Samples							
	37	34	38	36	39	21	40	23
BG/EPS ratios (wt/wt)								
BG(20-35 mesh)/EPS (mixed size)	100/0	85/15	100/0	85/15	100/0	85/15	100/0	85/15
Adhesives								
%UF (of dry particle weight)	15	15	-	-	15	15	-	-
%PF (of dry particle weight)	-	-	15	15	-	-	15	15
Target density (g/cm^3)	0.3	0.3	0.3	0.3	0.6	0.6	0.6	0.6
Hot pressing time (mins, at 100 °C)	10	10	10	10	10	10	10	10

3.4.8 Study on the Effect of BG Sizes

To investigate the effects of BG size, particleboards contained 15% of UF and PF of dry particle weight, BG/EPS ratio at 85/15 wt/wt and mixed EPS size were prepared at 10 minutes curing time and 0.3 g/cm^3 density. The test properties of particleboards made of BG size less than 20 mesh was compared with the 20-35 mesh (sample 34 and 36).

Table 3.9 Summary of samples based on BG sizes.

Items	Samples			
	34	41	36	42
BG/EPS ratio (wt/wt)				
BG (20-35 mesh)/EPS (mixed size)	85/15	-	85/15	-
BG (less than 20 mesh)/EPS (mixed size)	-	85/15	-	85/15
Adhesives				
%UF (of dry particle weight)	15	15	-	-
%PF (of dry particle weight)	-	-	15	15
Target density (g/cm^3)	0.3	0.3	0.3	0.3
Hot pressing time (mins, at 100 °C)	10	10	10	10

3.5 Test Methods

3.5.1 Bulk Density (JIS A 5908-1994)

The test pieces were measured the lengths, widths and thicknesses at the points as shown in Figure 3.6. After that their respective mean values were calculated. The volume (V) were calculated from above mean values. Then the mass (m) were weighed. The bulk density was calculated as the formula below. In this case, the thickness, length, width and mass shall be measured to the nearest of 0.05 mm, 0.1 mm, 0.1 mm and 0.1 g respectively. And the bulk density shall be calculated to the nearest of 0.01 g/cm^3. The number of test pieces shall be at least of five.

$$\text{Bulk Density (g/cm}^3\text{)} = \frac{m}{V} \qquad (3.1)$$

where m : mass (g)

V : volume (cm^3)

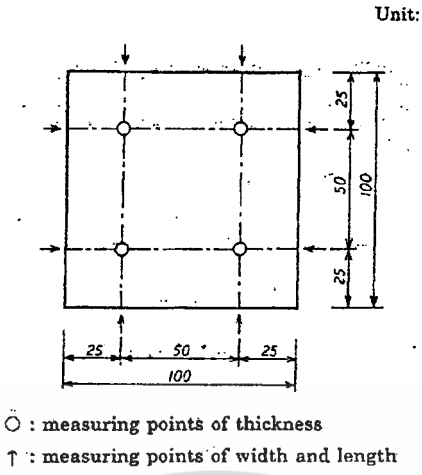


Figure 3.6 Points to be measured of lengths, widths and thicknesses

3.5.2 Water Absorption (TIS 876-2532)

The water soak test determines the water absorption behavior of the particleboards. The test pieces were preliminarily weighed the mass (m_1). After 24 hours of submersion in water at 20 ± 1 °C, horizontally about 3 cm below the water surface, the test pieces were weighed after the excess water drains off (m_2). The number of test pieces shall be at least of ten. The following calculation can then be made.

$$\text{Water absorption (\%)} = \frac{m_2 - m_1}{m_1} \times 100 \qquad (3.2)$$

where m_1 : mass (g) before water absorption

m_2 : mass (g) after water absorption

3.5.3 Thickness Swelling (JIS A 5908-1994)

The water soak test determines not only the water absorption behavior of the particleboards but also the effects of the absorbed water on particleboards dimensions. The test pieces were preliminarily measured the thickness (t_1) at four points midway along each side 25 mm. After 24 hours of submersion in water at 20 ± 1 °C, horizontally about 3 cm below the water surface, the thickness of test pieces were measured at the same four points and the average was obtained. Thickness swelling was calculated from the formula below. The number of test pieces shall be at least of ten.

$$\text{Thickness swelling (\%)} = \frac{t_2 - t_1}{t_1} \times 100 \quad (3.3)$$

where t_1 : thickness (mm) before water absorption

t_2 : thickness (mm) after water absorption

3.5.4 Bending Strength (Modulus of Rupture, MOR and Modulus of Elasticity, MOE) (JIS A 5908-1994)

Bending strength were measured by using the apparatus as shown in Figure 3.7. The loading bar was moved with a crosshead speed of 10 mm/min at a mean deformation speed from the surface of the test pieces. Modulus of Rupture (MOR) was calculated from the maximum load (P) as formula 3.4 below. The number of test pieces shall be at least of seven.

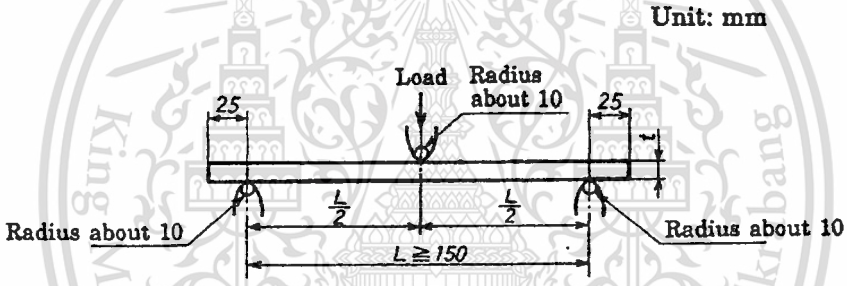


Figure 3.7 Test apparatus for bending strength

$$\text{MOR (MPa)} = \frac{3PL}{2bt^2} \quad (3.4)$$

where P : maximum load (N)

L : span (mm)

b : width of test piece (mm)

t : thickness of test piece (mm)

Calculation of Modulus of Elasticity (MOE) was calculated from the graph which plotted between maximum load (P) and deformation distance of test pieces. The obtained value of such maximum load (P) and deformation distance were measured in the range of linear line of graph. MOE was calculated from the formula 3.5 as below.

$$\text{MOE (MPa)} = \frac{L^3 \Delta W}{4bt^3 \Delta S} \quad (3.5)$$

where L : span (mm)

ΔW : increasing load in the range of linear line of graph (N)

ΔS : increasing bending distance in the range of linear line of graph (N)

b : width of test piece (mm)

t : thickness of test piece (mm)

3.5.5 Sound Absorption [23]

Apparatus :

1. Sound level meter : Model NL-14 of RION®, Japan
2. Sound testing room (1 m x 1 m x 2 m)
3. Power mixer : Model NPE AD-1524 of NPE Industry Co.,Ltd., Thailand
4. Audio generator : Model LAG-27 of Leader Electronic Corporation, Japan
5. Loud speaker (12 cm x 12 cm x 8 cm) : Sterea®

Loud speaker was put inside of sound testing room. Audio generator and power mixer were put outside of sound testing room. Then the above apparatus were connected together. Sound level meter was placed far from the exited area of the sound path of 10 cm as shown in Figure 3.8. Sound pressure level without any test pieces were measured at frequencies of 250, 500, 1000, 2000 and 4000 Hz by changing such frequencies at audio generator. Then the test pieces were placed inside of room at the exited area of the sound path. Sound pressure level with test pieces were measured at the same frequencies as mentioned above. The sound absorption were calculated from with and without test pieces at each frequency and express in the percentage of absorption.

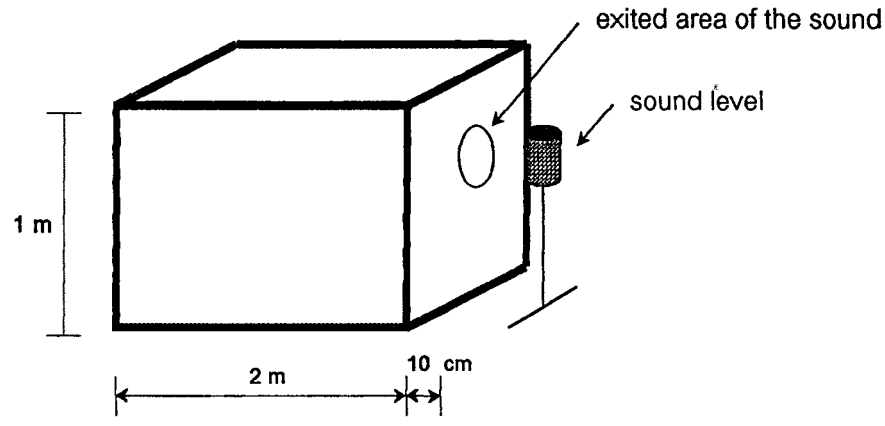


Figure 3.8 Sound absorption apparatus

3.5.6 Thermal Conductivity (ASTM C 177-85)

This test method covers the achievement and measurement of steady-state heat flux through flat-slab specimens by using a guarded-hot-plate apparatus. The method encompasses both the single-sided and the double-sided mode of measurement. Figure 3.9 illustrates the core components of the idealized system: two isothermal cold surface units and a guarded isothermal hot-surface unit. The guarded isothermal hot-surface unit is composed of the metered area unit and a concentric guard unit. Sandwiched between these three units is the material to be measured, that is, the test piece. The metered area unit is the portion of the assembly that provides the power (heat flow per unit time) for the measurement and defines the actual test volume, that is, that portion of the test piece that is actually being measured.

Apparatus :

1. Guarded-hot-plate apparatus
2. Guarded heating unit
3. Cooling/auxiliary heating units
4. Secondary guarding
5. Temperature measuring and control sensors
6. Thickness measurement
7. Power to metered region

The test pieces, secondary guarding and an environmental chamber (if necessary) were installed in apparatus. The various heating and cooling units were placed into operation to achieve

the test temperature conditions (around 30 °C). The time required to achieve thermal steady-state, in case low conductance of test pieces, the settling time was on the order of hours. Settling times generally increased with thicker of test pieces, specimens with low thermal diffusivity, and the mass of the guarded heater. After achieve of the desired steady-state, three successive repeat data acquisition runs shall be completed. These runs shall be conducted at intervals of no less than 30 mins. Thermal conductivity was calculated by the formula below.

$$\lambda = \frac{Q}{A} \times \frac{d}{\Delta T} \tag{3.6}$$

where λ : thermal conductivity (W/m k)

Q : heater power (Watt)

d : the average thickness of the test piece (m)

A : area bounded by the middle of the guard/center gap (m^2)

ΔT : the average temperature drop through the test piece thickness (K)

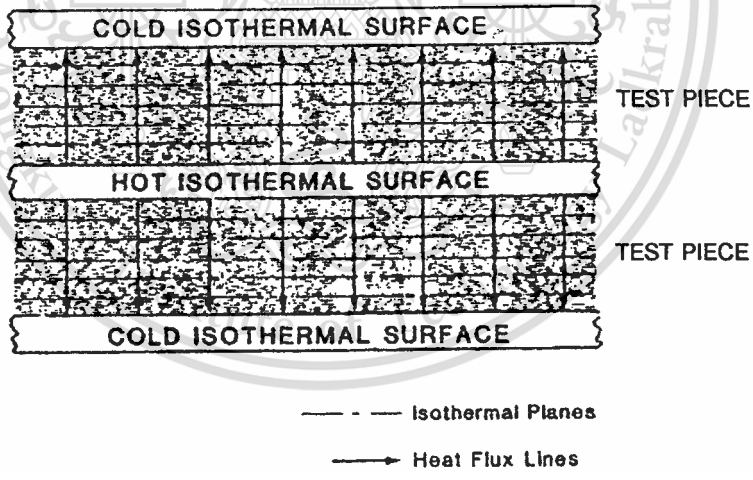


Figure 3.9 Schematic of the Guarded-hot-plate apparatus

CHAPTER 4

EXPERIMENTAL RESULTS

4.1 Effect of Adhesive Quantities on Physical Appearance

Quantities of adhesive play a key role in the appearance of the finishing boards. If the edges of boards are not slip-loose, it means that such quantity of adhesive is suitable for bonding the particles. The result suggested that the more adhesive, the less slip-loosed edges. When more adhesives were added, it triggers to the well bonded surface and nonslip-loosed edges.

Particleboards were formed by using BG/EPS ratio at 90/10 wt/wt, EPS of 2-3 mm and BG of 20-35 mesh. Different adhesives used were 6, 9, 12, 15, 20, 25 and 30% of dry particle weight. The target board density was at 0.3 g/cm^3 and curing condition at 100 °C for 5 minutes. The result of mechanical properties are given in Table 4.1 and Figure 4.2-4.3. MOR and MOE gave an information about strength of particleboards.

Table 4.1 (a) Properties of particleboards with various quantities of UF and PF

Properties	Samples						
	1	2	3	4	5	6	7
	6% UF	9% UF	12% UF	15% UF	20% UF	25% UF	30% UF
Board density (g/cm^3)	0.30	0.31	0.30	0.30	0.31	0.29	0.30
Physical appearance	Poor slip-loosed edge	Poor slip-loosed edge	Poor slip-loosed edge	Fair slip-loosed edge	Without slip-loosed edge	Without slip-loosed edge	Without slip-loosed edge
Bending - MOR (MPa)	0.27	0.45	0.68	0.90	1.22	1.60	2.05
- MOE (MPa)	27.63	40.51	55.50	81.93	101.59	132.07	176.75

Table 4.1 (b) Properties of particleboards with various quantities of UF and PF (to)

Properties	Samples						
	8	9	10	11	12	13	14
	6% PF	9% PF	12% PF	15% PF	20% PF	25% PF	30% PF
Board density (g/cm^3)	0.31	0.29	0.30	0.31	0.31	0.30	0.32
Physical appearance	Poor slip-loosed edge	Poor slip-loosed edge	Fair slip-loosed edge	Without slip-loosed edge	Without slip-loosed edge	Without slip-loosed edge	Without slip-loosed edge
Bending - MOR (MPa)	0.43	0.88	1.33	1.62	2.23	3.44	4.86
- MOE (MPa)	41.94	62.98	96.87	124.48	181.23	253.89	328.54

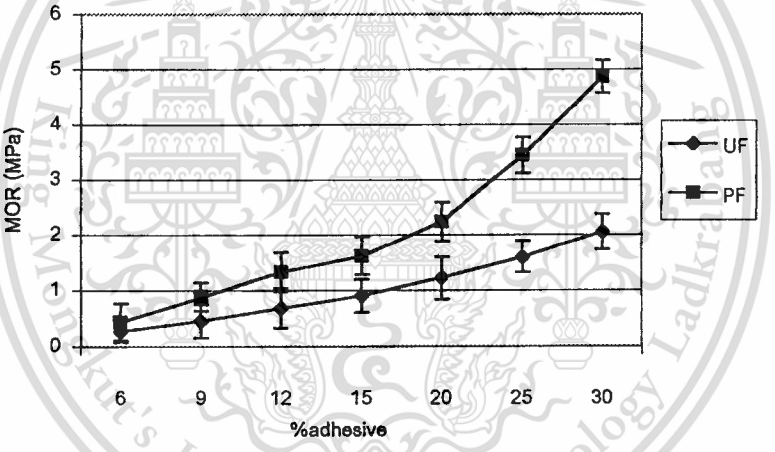


Figure 4.1 MOR (Modulus of Rupture) vs %UF and PF on dry particle weight

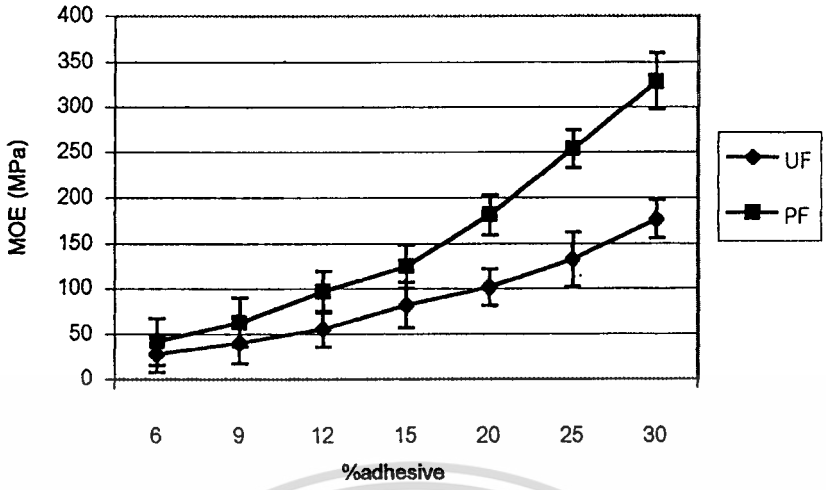


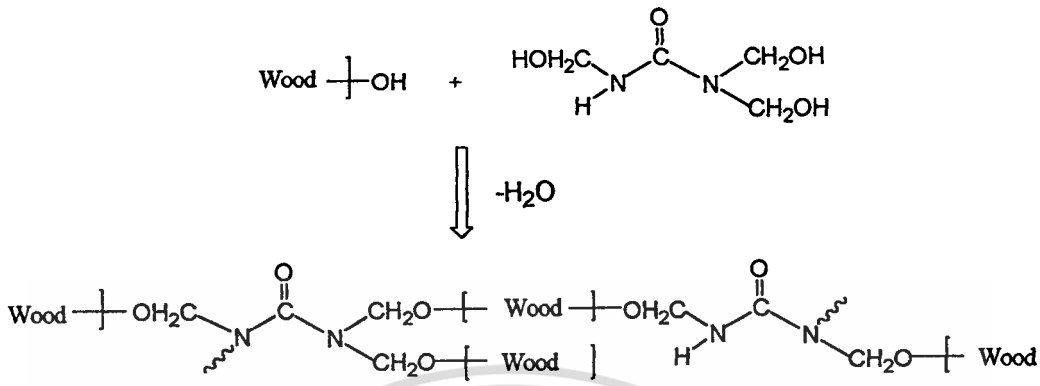
Figure 4.2 MOE (Modulus of Elasticity) vs %UF and PF on dry particle weight

The effect of adhesive quantities on MOR is shown in Figure 4.1. MOR increased by increasing adhesive quantities. This implied that polar functional groups of UF and PF hold BG/EPS particles together. When the surfaces of particles were covered sufficiently with adhesives, bond strength between particles and adhesives became strong. Consequently, particleboards could absorb and well dissipate loading force.

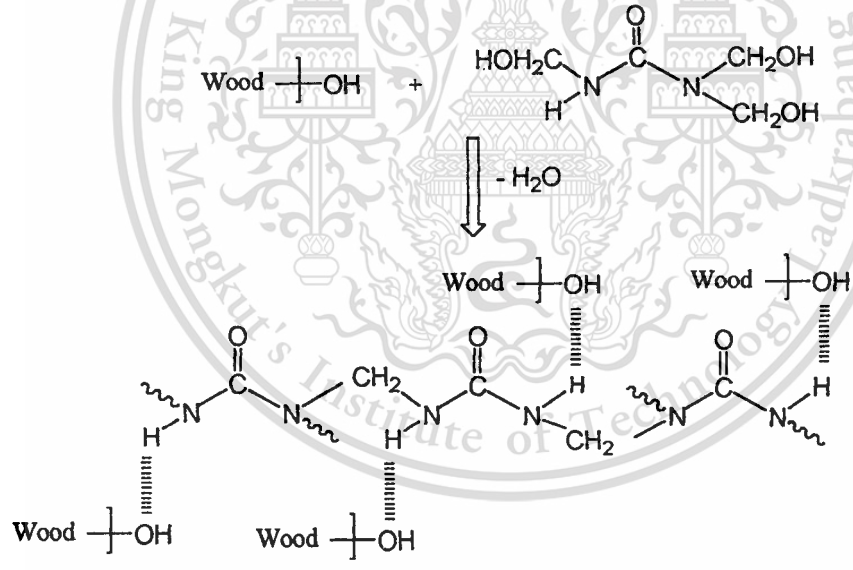
The MOR of PF boards was higher than that of UF boards. This result indicated that PF adhesive provided higher bond strength than UF adhesive. Therefore, PF boards could absorb and well dissipate loading force.

The possible adhesion mechanisms of the experimental particleboards are as follows.

- Between BG with UF : The possible bonding were covalent and hydrogen bond.

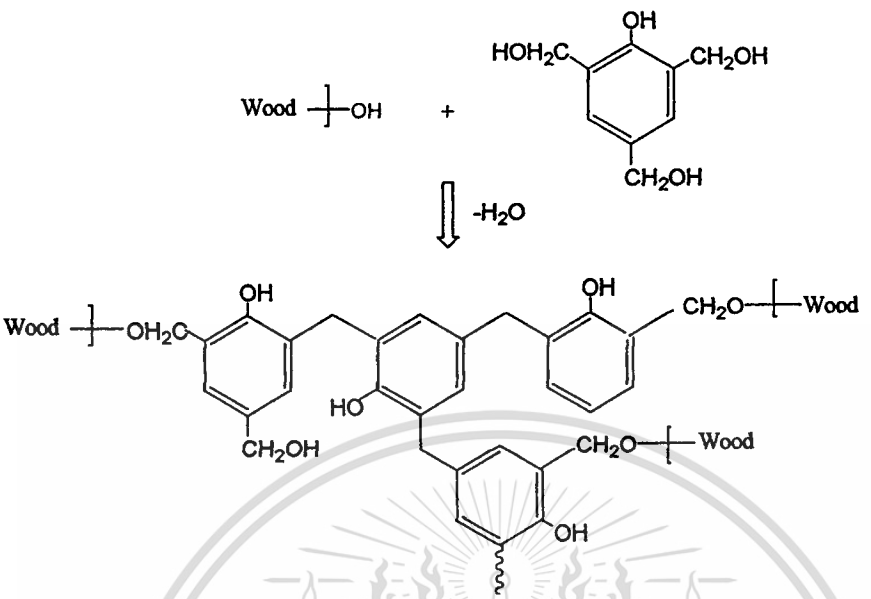


Covalent bond

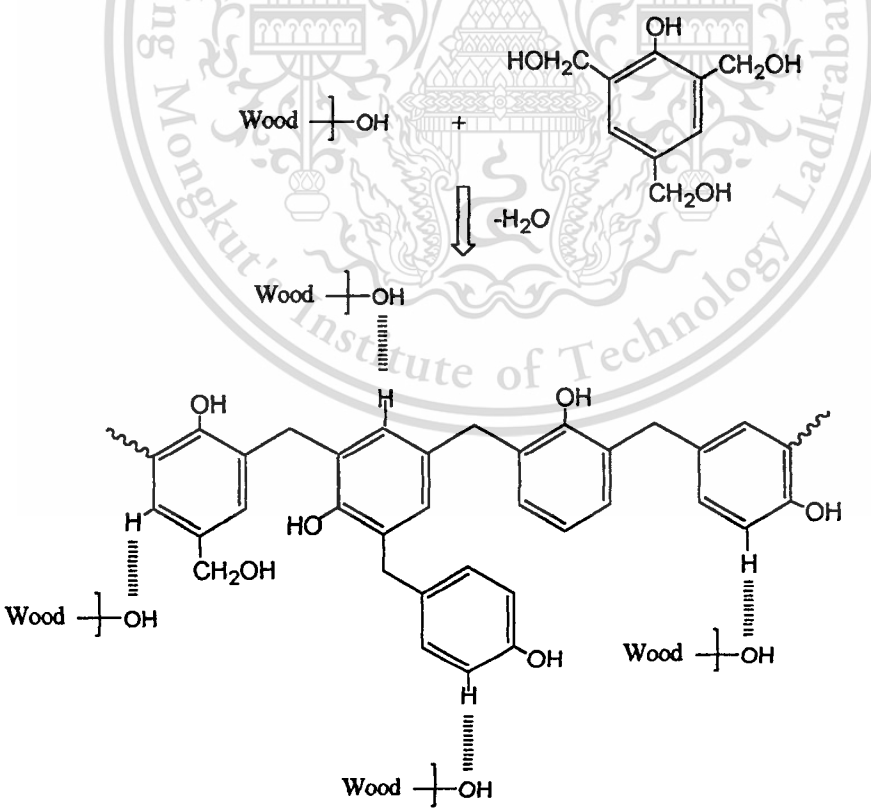


Hydrogen bond

- Between BG with PF : The possible bonding were covalent and hydrogen bond.



Covalent bond



Hydrogen bond

- Between either BG or adhesives and EPS

The adhesion mechanism between either BG or adhesives and EPS was mechanical interlocking. That means EPS' porous and coarse surface of BG fibers invariably intertwined their structures together. Moreover, adhesives penetrated into fiber walls of BG and EPS to form mechanical interlocking.

The effect of adhesive quantities on MOE is shown in Figure 4.2. It showed that MOE had the same trend as MOR. MOE also increased by increasing adhesive quantities. MOE of PF boards was higher than that of UF boards.

Eventhough, particleboards which used 15% of UF and PF, showed fair and not slip loose at the edges of boards and gave fair MOR and MOE. We selected 15% of UF and PF for further experiment because using higher adhesive quantities might increase the cost of production.

4.2 Effect of Ratios of BG to EPS

Mechanical and physical properties of particleboards prepared from the samples 15-20 as shown in Table 3.3 are given in Table 4.2.

Table 4.2 Properties of particleboards with various ratios of BG/EPS

Properties	Samples					
	15	16	17	18	19	20
	95/5, UF	90/10, UF	85/15, UF	95/5, PF	90/10, PF	85/15, PF
Board density (g/cm^3)	0.62	0.63	0.63	0.62	0.60	0.61
Bending - MOR (MPa)	5.13	5.60	6.71	7.08	8.38	9.22
- MOE (MPa)	455.94	483.93	520.05	540.11	587.56	640.04
Water absorption 24 hrs (%)	105.8	92.5	70.2	74.3	68.1	50.5
Thickness swelling 24 hrs (%)	14.6	13.9	11.5	7.9	6.8	5.8
Sound absorption (%)						
250 Hz	3.33	3.48	3.60	4.03	3.98	4.01
500 Hz	2.86	2.51	2.42	2.74	3.21	2.98
1000 Hz	11.39	11.52	11.44	11.89	12.02	12.04
2000 Hz	16.22	16.47	16.60	16.12	16.19	16.30
4000 Hz	18.00	18.05	18.28	18.48	18.70	18.87

4.2.1 Water Absorption

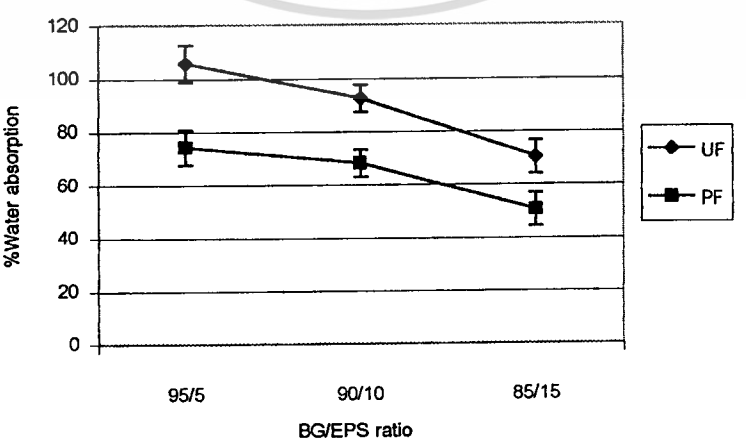


Figure 4.3 %Water absorption vs BG/EPS ratios

The effect of BG/EPS ratios on water absorption is shown in Figure 4.3. The highest water absorption found at BG/EPS : 95/5 wt/wt. Whereas BG/EPS ratio at 85/15 wt/wt showed lowest water absorption. This means that water absorption varied to the amount of BG as BG are cellulose which composed of hydroxy groups. Normally, hydroxy groups can easily absorb water and thus, when the amount of BG increased, water absorption also increased as well. In contrast, EPS is a hydrocarbon polymer which could not absorb water; consequently, water absorption was inversely affected by the amount of EPS.

With regard to water absorption, UF boards were higher than PF boards. The adhesion of UF resins to cellulose is sensitive to water not only the methylene bridges linking, the nitrogens of amido groups can be split rather easily by water attack in UF resin and of its partial reversibility [27], but also because theoretical calculations have shown that on most cellulose sites the average adhesion of water to cellulose is stronger than that of UF oligomers. Thus water can displace hardened UF resins from the surfaces of a wood joints. The inverse effect is valid for PF resin which shows complete resistance to hydrolysis of the C-C bonds between the aromatic nucleus and the methylene bridges [27]. For those reasons water absorption of UF boards was higher than that of PF boards.

4.2.2 Thickness Swelling

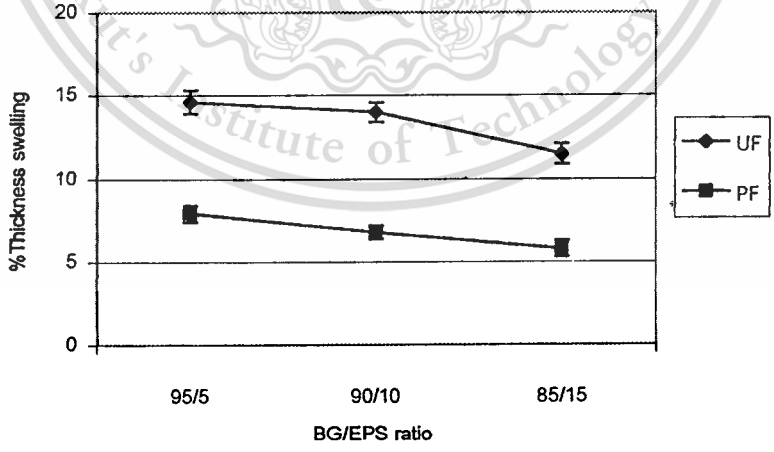


Figure 4.4 %Thickness swelling vs BG/EPS ratios

After soaking UF and PF particleboards in water, the dimensions of boards were determined. Figure 4.4 shows the relationship between thickness swelling and various BG/EPS ratios. In this

graph, BG/EPS ratio at 95/5 wt/wt gave the highest thickness swelling and BG/EPS ratio at 85/15 wt/wt gave the lowest. The results suggested that thickness swelling varied to the amount of BG as well as water absorption.

It was found that thickness swelling of UF boards was higher than that of PF boards. As previously described, thickness swelling depends on bond qualities and adhesive properties [24]. Thus, the weaker bond of UF boards resulted in the higher thickness swelling.

4.2.3 MOR and MOE

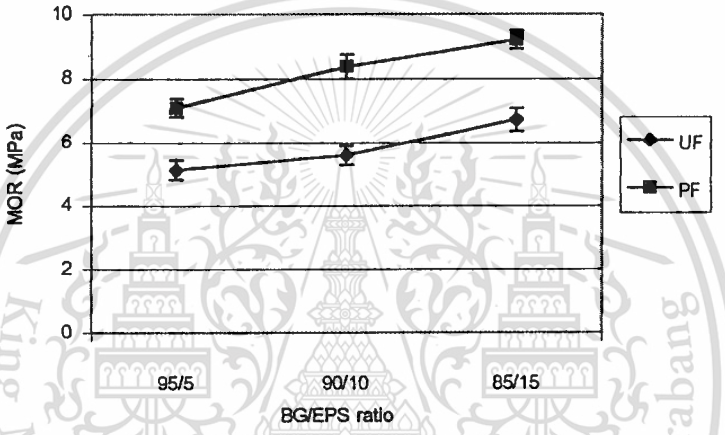


Figure 4.5 MOR (Modulus of Rupture) vs BG/EPS ratios

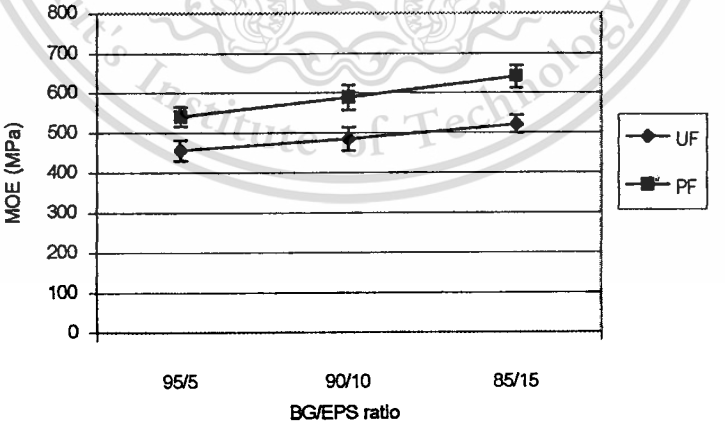


Figure 4.6 MOE (Modulus of Elasticity) vs BG/EPS ratios

The relationship between MOR and various BG/EPS ratios is shown in Figure 4.5. The results showed that BG/EPS ratio at 85/15 wt/wt yielded the highest MOR while BG/EPS ratio at

95/5 wt/wt yielded the lowest MOR. These aspect MOR means that MOR varied to the amount of EPS. This is probably because the dispersion of adhesives showed well by substituting of EPS. Since EPS is a nonpolar polymer, it contributed electrostatic during blending process. The agglomeration of BG with adhesives in BG/EPS ratio at 85/15 wt/wt was less than that of BG/EPS ratio at 95/5 wt/wt. So the higher amount of EPS, the better dispersion of mixture. Consequently, MOR of higher amount of EPS showed higher than that of lower amount of EPS.

In comparing MOR of PF boards and UF boards, the results showed that the first type of boards expressed higher MOR than the second type of boards. This is probably because bond strength of PF boards was higher than that of UF boards. Hence, they could absorb and well dissipate loading force.

Figure 4.6 shows MOE against various BG/EPS ratios. MOE showed a similar trend as MOR, that are, MOE increased by increasing the amount of EPS. Besides, this MOE of PF boards was higher than that of UF boards.

4.2.4 Sound Absorption

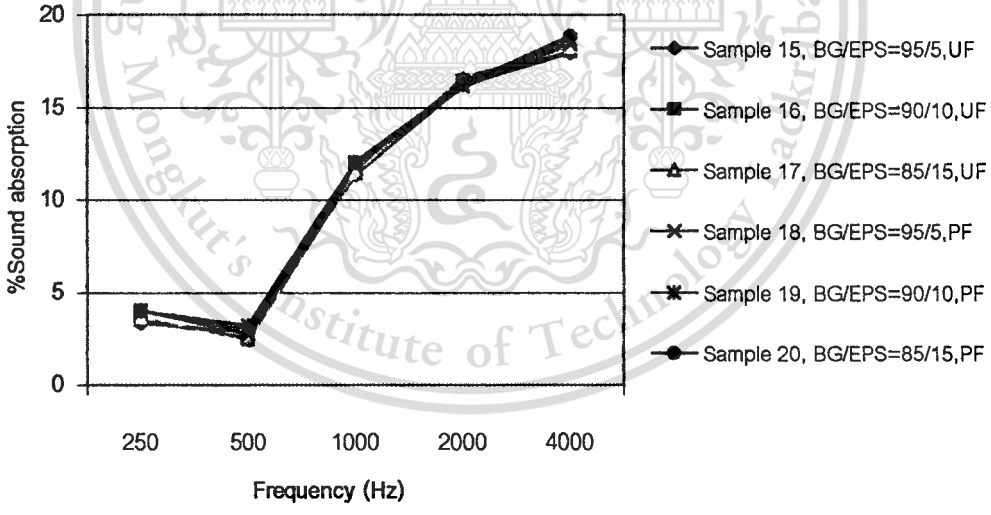


Figure 4.7 %Sound absorption vs frequency for various BG/EPS ratios

The effect of various types of BG/EPS ratios on sound absorption is shown in Figure 4.7. Sound absorption of those three ratios was nearly the same. It means that sound absorption did not depend on the ratios of BG/EPS. In general, the porous materials have good sound absorption properties [25] because they have open pore structures. When sound wave passes through materials, air molecules are vibrated and forced through the pores. Then they interact with the

pore wall, and frictional losses convert some of sound energy to heat energy [16,18]. However, those three ratios of BG/EPS had slightly the same densities so they had slightly the same porosities.

In addition to what have been previously described, frictional losses converted sound energy to heat energy, there were also relaxation losses due to the deformation of the particles [19]. The relaxation relates to bond strength which is higher in PF boards. According to the C-C bonds between aromatic nucleus and methylene bridges of PF resin are higher stable than methylene bridges of UF resin [27]. For these reasons, PF boards were less relaxation losses than UF boards which resulted in higher decreasing sound wave intensity. Consequently, sound absorption of PF boards showed higher than that of UF boards. However, densities of those two type of boards were slightly different thus they were not significantly different in their porosities. Therefore, PF boards provided sound absorption property slightly higher than that of UF boards.

In summary, particleboards which used BG/EPS ratio at 85/15 wt/wt, showed optimum properties. So such ratio was chosen for further experiment of this study.

4.3 Effect of EPS Sizes

Sizes of EPS such as diameter of 2-3 mm, mixed size and diameter of 3-6 mm were used for the preparation of particleboards. BG/EPS ratio at 85/15 wt/wt, curing time at 100 °C for 10 minutes, 15% of UF and PF of dry particle weight as well as 20-35 mesh BG were used as well. The target density of this study particleboard was 0.6 g/cm^3. It is because this study would like to compare particleboard properties with general commercial gypsum board. Additionally density of such gypsum board one brand in Thailand is in range of 0.6-0.7 g/cm^3 (obtained by measuring the actual pieces of such gypsum board as according to JIS A 5908-1994). The results are given in Table 4.3.

Table 4.3 Properties of particleboards with various sizes of EPS

Properties	Samples					
	17	21	22	20	23	24
	2-3 mm, UF	Mixed size, UF	3-6 mm, UF	2-3 mm, PF	Mixed size, PF	3-6 mm, PF
Board density (g/cm^3)	0.63	0.62	0.60	0.61	0.61	0.62
Bending - MOR (MPa)	6.71	7.05	6.27	9.22	9.70	9.83
- MOE (MPa)	520.05	531.11	498.43	640.04	633.05	601.56
Water absorption 24 hrs (%)	70.2	73.3	74.5	50.5	48.0	55.2
Thickness swelling 24 hrs (%)	11.5	11.1	10.1	5.8	5.6	6.1
Sound absorption (%)						
250 Hz	3.60	3.63	3.54	4.01	4.11	4.24
500 Hz	2.42	2.87	2.96	2.98	3.02	3.08
1000 Hz	11.44	11.71	11.53	12.04	12.05	12.22
2000 Hz	16.60	16.41	16.45	16.30	16.26	16.54
4000 Hz	18.28	18.28	18.31	18.87	18.28	18.45

4.3.1 Water Absorption

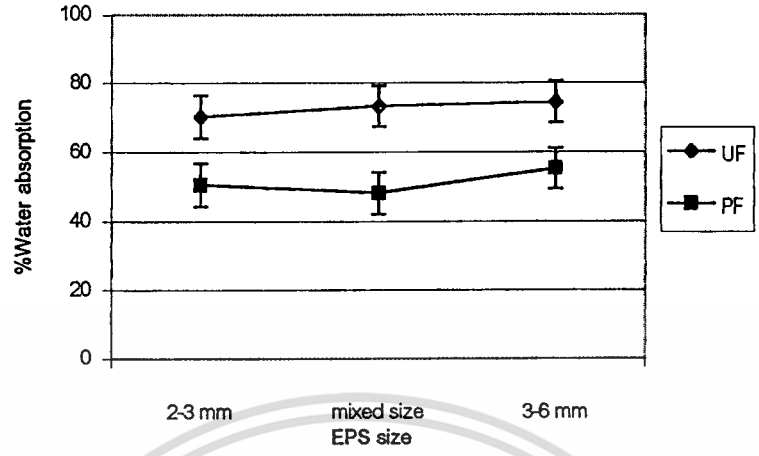


Figure 4.8 %Water absorption vs EPS sizes

The effect of various EPS sizes on water absorption is shown in Figure 4.8. It was found that water absorption of such three sizes for both UF and PF had slightly different. It can be seen that the sizes of EPS did not show significant difference on porosities in boards. In fact, EPS is a nonpolar polymer and has no interaction with water.

With regard to water absorption, UF boards were higher than PF boards. The reason is described in 4.2.1.

4.3.2 Thickness Swelling

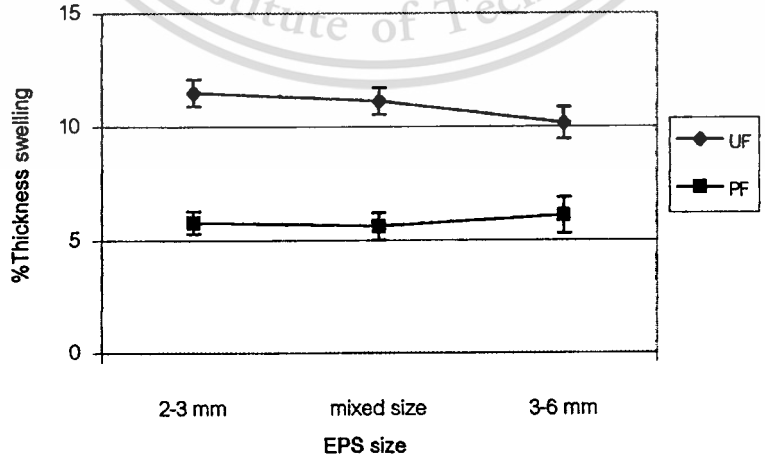


Figure 4.9 %Thickness swelling vs EPS sizes

Figure 4.9 shows the relationship between thickness swelling with various sizes of EPS after soaking boards in water. Thickness swelling of those three sizes of EPS boards for each adhesive was slightly different. The reasons are described the same as in water absorption property.

However, thickness swelling of UF boards was relatively higher than that of PF boards because bonding strength of UF boards was weaker than that of PF boards.

4.3.3 MOR and MOE

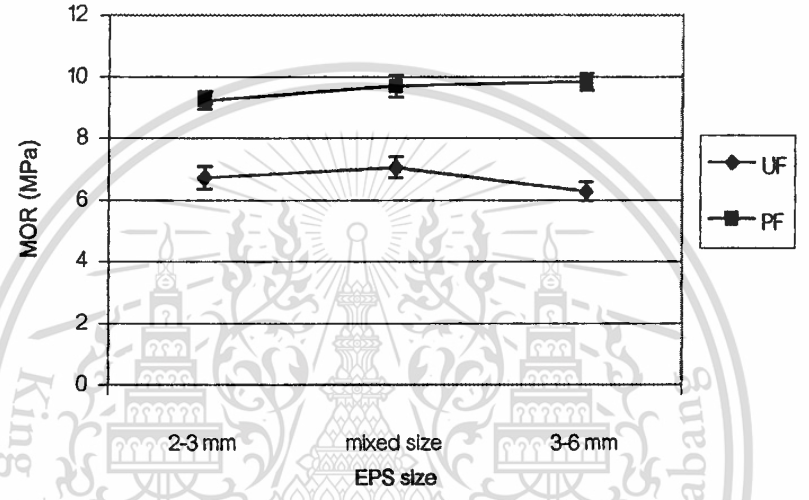


Figure 4.10 MOR (Modulus of Rupture) vs EPS sizes

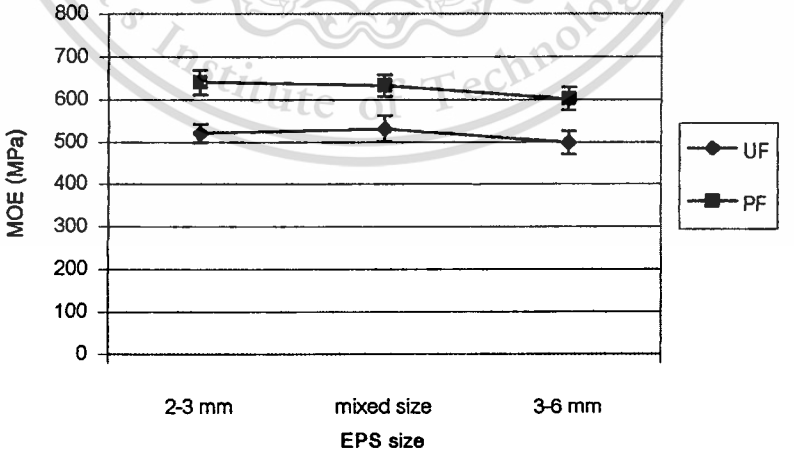


Figure 4.11 MOE (Modulus of Elasticity) vs EPS sizes

MOR of different sizes of EPS was slightly different as shown in Figure 4.10. Probably, this is because the amount of used EPS was the same and the sizes of EPS were not obviously different. Therefore, the ability of absorbed and dissipated loading force was almost the same.

However, MOR of PF boards was higher than that of UF boards. Because bonding strength of PF boards was higher than that of UF boards. Hence, they could absorb and well dissipate loading force.

MOE of different sizes of EPS showed a similar trend as MOR which are shown in Figure 4.11. The results showed that MOE of different sizes of EPS was slightly different and MOE of PF boards was higher than that of UF boards.

4.3.4 Sound Absorption

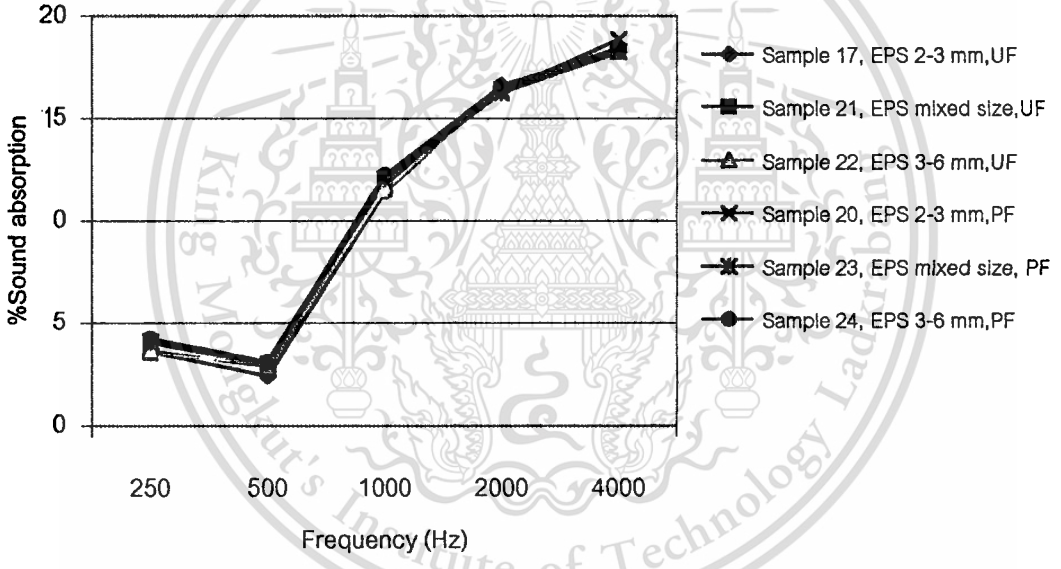


Figure 4.12 %Sound absorption vs frequency for various EPS sizes

Comparison sound absorption of various sizes of EPS are shown in Figure 4.12. Sound absorption was independent from sizes of EPS. This is probably because EPS were compressed during pressing process. Hence, their sizes became decreased or their sizes were not significantly different. As a result, sound absorption of those sizes of EPS was almost the same.

PF boards were little higher sound absorption than UF boards. The reason described in 4.2.4.

In summary, particleboards which used the mixed size EPS, showed nearly similar properties as EPS of 2-3 mm and EPS of 3-6 mm. In addition, mixed size EPS was easy to prepare because

it was no need to screen size. It was ready-to-use after grinding. So mixed size of EPS was chosen for further experiment.

4.4 Effect of Curing Times

To study effect of curing times, different curing times at 5, 10 and 15 minutes were used. Particleboards were formed by using BG/EPS ratio at 85/15 wt/wt, mixed size EPS, hot pressing at 100 °C, 15% of UF and PF of dry particle weight as well as 20-35 mesh BG. The target board density was 0.6 g/cm^3. The results are given in Table 4.4.

Table 4.4 Properties of particleboards with various curing times

Properties	Samples					
	25	21	26	27	23	28
	5 mins, UF	10 mins, UF	15 mins, UF	5 mins, PF	10 mins, PF	15 mins, PF
Board density (g/cm^3)	0.60	0.62	0.61	0.61	0.61	0.59
Bending - MOR (MPa)	6.44	7.05	8.10	7.20	9.70	10.83
- MOE (MPa)	490.32	531.11	545.78	429.09	633.05	670.93
Water absorption 24 hrs (%)	83.2	73.3	65.5	62.6	48.0	40.8
Thickness swelling 24 hrs (%)	13.1	11.1	9.8	7.5	5.6	4.7
Sound absorption (%)						
250 Hz	3.48	3.63	3.65	3.99	4.11	4.25
500 Hz	2.47	2.87	2.91	2.89	3.02	2.93
1000 Hz	11.33	11.71	12.20	11.62	12.05	12.86
2000 Hz	15.64	16.41	17.49	16.03	16.26	17.79
4000 Hz	17.62	18.28	18.98	17.68	18.28	19.67

4.4.1 Water Absorption

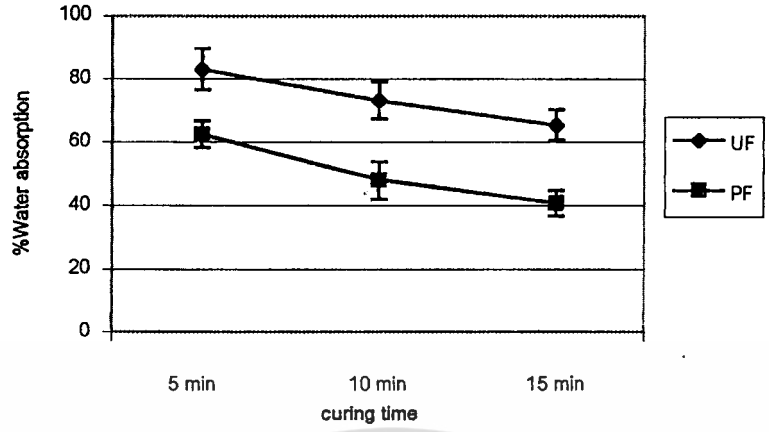


Figure 4.13 %Water absorption vs curing times

The effect of various curing times on water absorption both in UF and PF, is shown in Figure 4.13. The observation found the lowest water absorption was at 15 minutes while at 5 minutes showed the highest. This means that water absorption was inversely proportional to curing times. Heat transfer was taken place from board surfaces into core layer during the hot pressing so the longer pressing time, the more complete curing. The complete curing resulted in high bonding strength, therefore, water absorption was less.

With regard to water absorption, UF boards were higher than PF boards. The reason described in 4.2.1.

4.4.2 Thickness Swelling

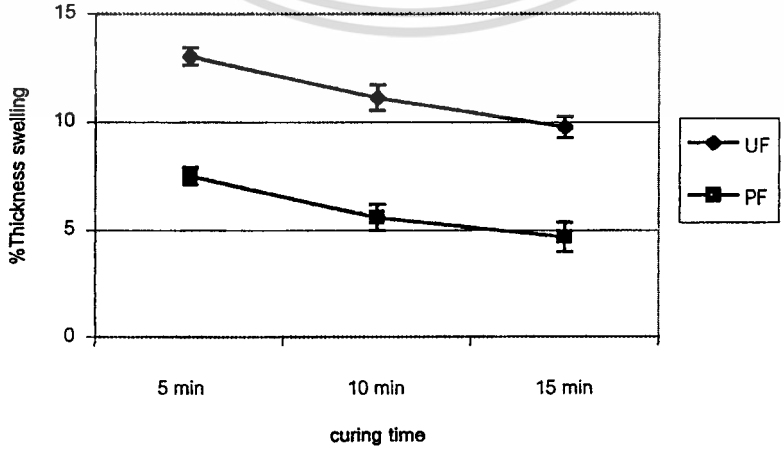


Figure 4.14 %Thickness swelling vs curing times

Figure 4.14 shows thickness swelling of UF and PF boards with different curing times. Thickness swelling showed the same trend as water absorption. The results showed that thickness swelling decreased by increasing curing times. Therefore, 15 minutes provided the lowest value.

Thickness swelling of UF boards was higher than that of PF boards because as previously described. Thickness swelling is dependent on types and quantities of adhesives. Thus, the weaker bond of UF boards, the higher thickness swelling.

4.4.3 MOR and MOE

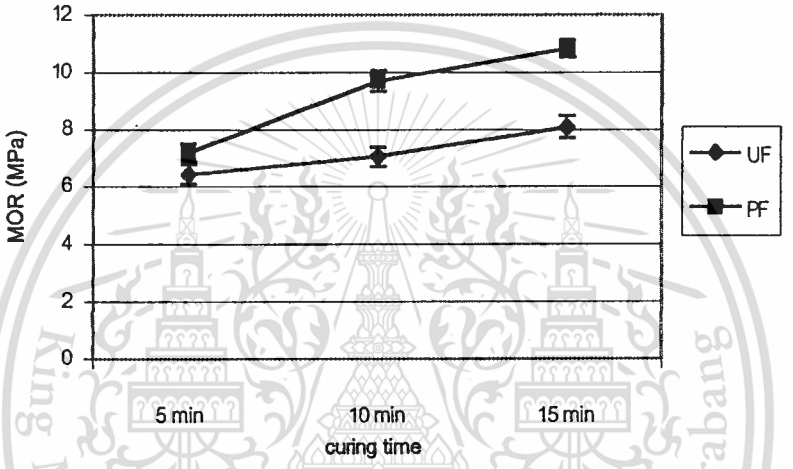


Figure 4.15 MOR (Modulus of Rupture) vs curing times

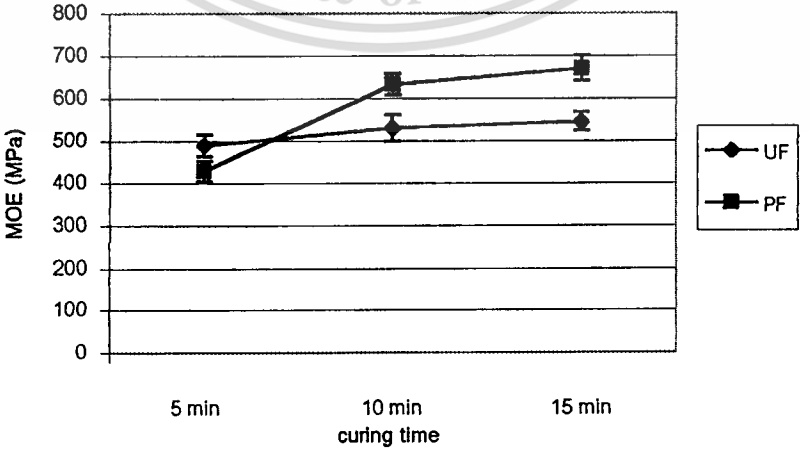


Figure 4.16 MOE (Modulus of Elasticity) vs curing times

The effect of curing times on MOR is shown in Figure 4.15. It was found that at 15 minutes showed the highest MOR while at 5 minutes showed the lowest. MOR of higher curing time boards could absorb and well dissipate loading force.

In comparing MOR of PF boards and UF boards, MOR of PF boards was higher than that of UF boards.

MOE of different curing times reflected the same trend as MOR (Figure 4.16). It was seen that MOE varied proportionally to curing times and MOE reflected of PF boards was higher than that of UF boards.

4.4.4 Sound Absorption

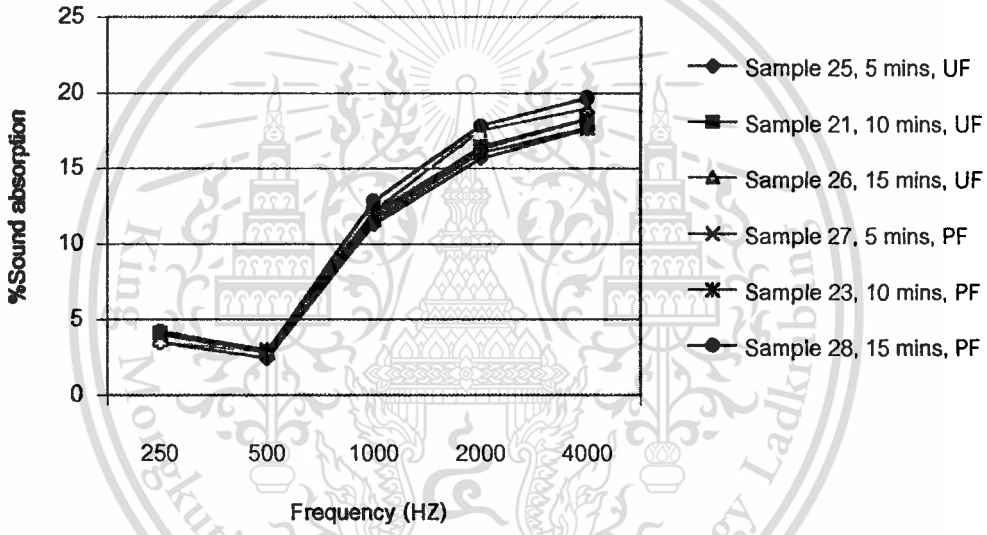


Figure 4.17 %Sound absorption vs frequency for various curing times

Sound absorption increased by curing time increasing (Figure 4.17). In fact, the mechanisms of sound absorption are related not only to the frictional losses by converting sound energy to heat energy in porous materials [25] but also, related to less deformation of particles and less relaxation losses [19]. As a result, sound wave intensity decrease. However, relaxation losses decrease by increasing curing time as mention before. So the higher pressing time, the higher sound absorption.

PF boards had little higher sound absorption than UF boards. The reason described in 4.2.4.

In summary, particleboards which cured at 100 °C for 15 minutes, manifested optimum properties. Whereas those cured for 10 minutes and 5 minutes were gradually decreased degree of their properties. However, the curing time commonly used in the particleboard manufacturing is 6 minutes per 10 mm of thickness [28]. So 9 mm of thickness of this study should be used curing time around 5-6 minutes. However, we found that the properties of particleboards of such curing time were still rather low. In fact, the longer time used, the higher cost production. So the selected curing time for further experiment should be 10 minutes. Moreover, their properties were still acceptable.

4.5 Effect of Adhesive Quantities

Adhesives at 7, 11 and 15% of dry particle weight, BG/EPS ratio at 85/15 wt/wt, mixed size EPS, curing time at 100 °C for 10 minutes and BG of 20-35 mesh were formed particleboards. The target board density was 0.6 g/cm^3. The results are given in Table 4.5.

Table 4.5 Properties of particleboards with various quantities of UF and PF

Properties	Samples					
	29	30	21	31	32	23
	7%UF	11%UF	15%UF	7%PF	11%PF	15%PF
Board density (g/cm^3)	0.59	0.60	0.62	0.60	0.59	0.61
Bending - MOR (MPa)	2.24	4.92	7.05	4.94	7.20	9.70
- MOE (MPa)	205.05	377.95	531.11	315.14	498.08	633.05
Water absorption 24 hrs (%)	144.4	106.0	73.3	112.2	70.7	48.0
Thickness swelling 24 hrs (%)	72.6	33.9	11.1	37.6	19.6	5.6
Sound absorption (%)						
250 Hz	4.89	4.16	3.63	4.88	4.32	4.11
500 Hz	3.05	2.90	2.87	3.13	3.04	3.02
1000 Hz	13.26	12.08	11.71	13.55	12.61	12.05
2000 Hz	19.26	17.00	16.41	19.62	17.84	16.26
4000 Hz	19.81	18.87	18.28	20.45	19.69	18.28

4.5.1 Water Absorption

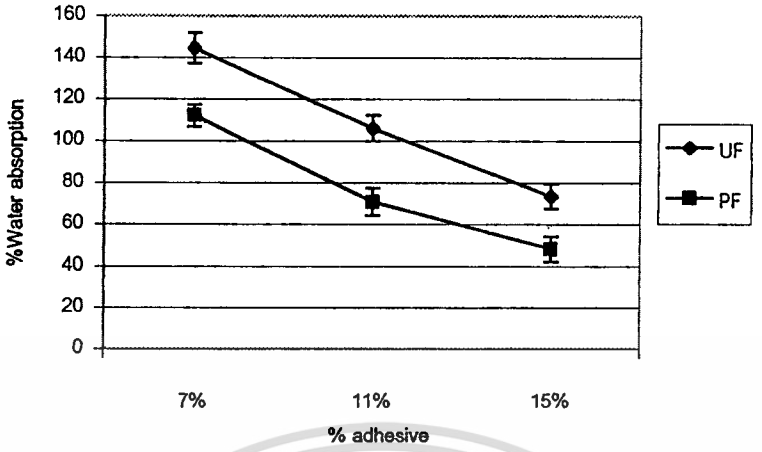


Figure 4.18 %Water absorption vs %adhesive of UF and PF

Figure 4.18 shows the effect of different quantities of UF and PF on water absorption. The boards with 15% of adhesive gave the lowest water absorption, whereas the boards with 7% gave the highest. Similarly, water absorption decreased by increasing adhesive quantities [4] as adhesive quantities cause higher numbers of spot welding between particles and adhesive. Consequently, water was less absorbed to particles especially in cellulose of BG.

With regard to water absorption, UF boards were higher than that of PF boards. The reason described in 4.2.1.

4.5.2 Thickness Swelling

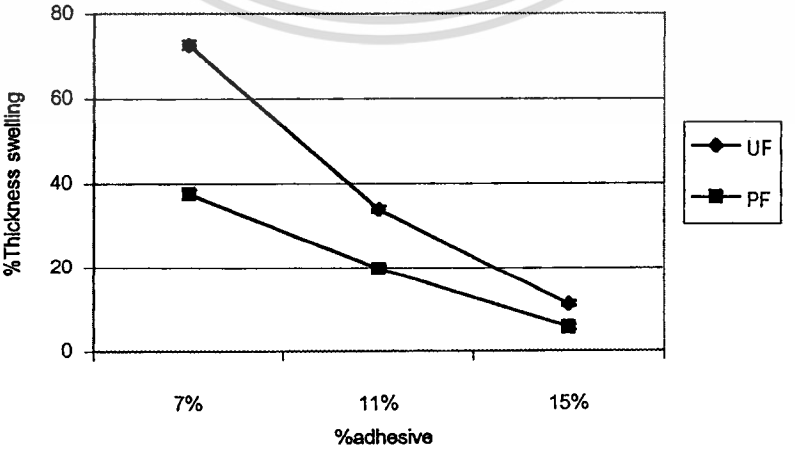


Figure 4.19 %Thickness swelling vs %adhesive of UF and PF

After soaking, the dimensions of boards were determined. Figure 4.19 shows the relationship between thickness swelling and various adhesive quantities. In this graph, thickness swelling of 15% of adhesive showed the lowest, while the boards with 7% of adhesive showed the highest. Thickness swelling varied proportionally to adhesive quantities. This property showed a similar trend to water absorption.

However, thickness swelling of UF boards was higher than that of PF boards as previously described. Thickness swelling is related to bond qualities and adhesive properties [24]. Hence, the weaker and polar bond of UF boards caused the higher thickness swelling.

4.5.3 MOR and MOE

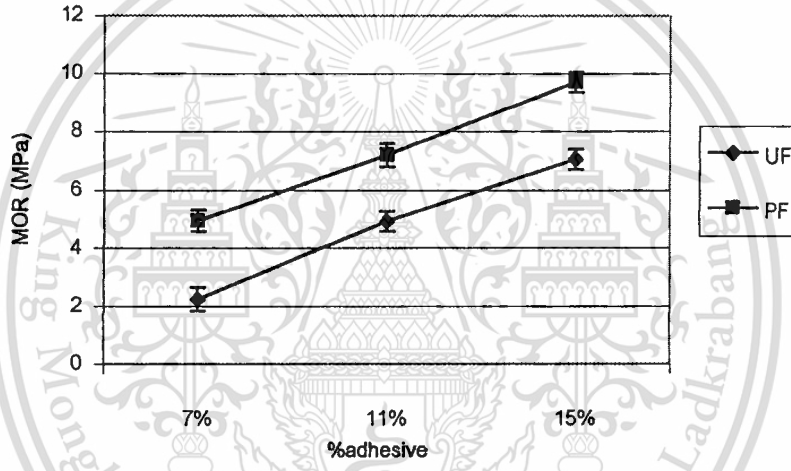


Figure 4.20 MOR (Modulus of Rupture) vs %adhesive of UF and PF

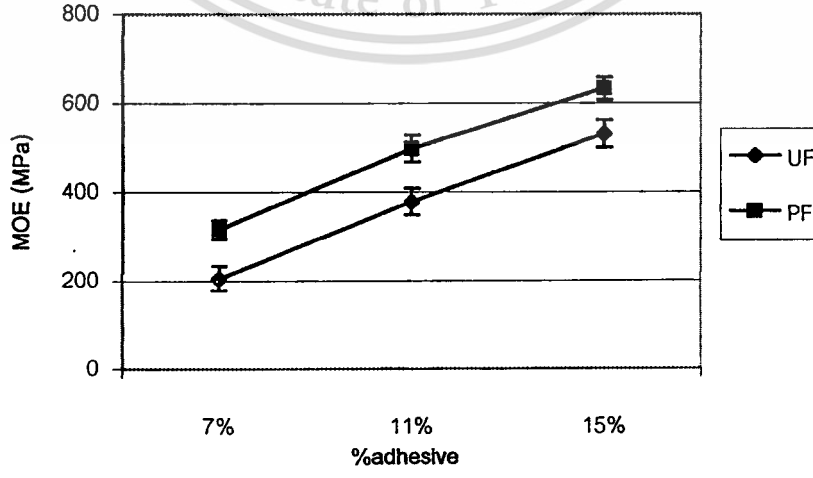


Figure 4.21 MOE (Modulus of Elasticity) vs %adhesive of UF and PF

The effect of adhesive quantities on MOR is shown in Figure 4.20. MOR of 15% of adhesive boards showed the highest while 7% of adhesive boards showed the lowest. This means that MOR varied proportionally to adhesive quantities. Normally, function of adhesive should be capable of holding particles together [13]. Higher adhesive quantities induced higher bonding strength. As a result, boards could absorb and well dissipate loading force when a load was applied to.

MOR of PF boards was higher than that of UF boards because of the higher bonding strength of PF boards. Hence, PF boards could absorb and well dissipate loading force.

MOE showed a similar trend to MOR as shown in Figure 4.21.

4.5.4 Sound Absorption

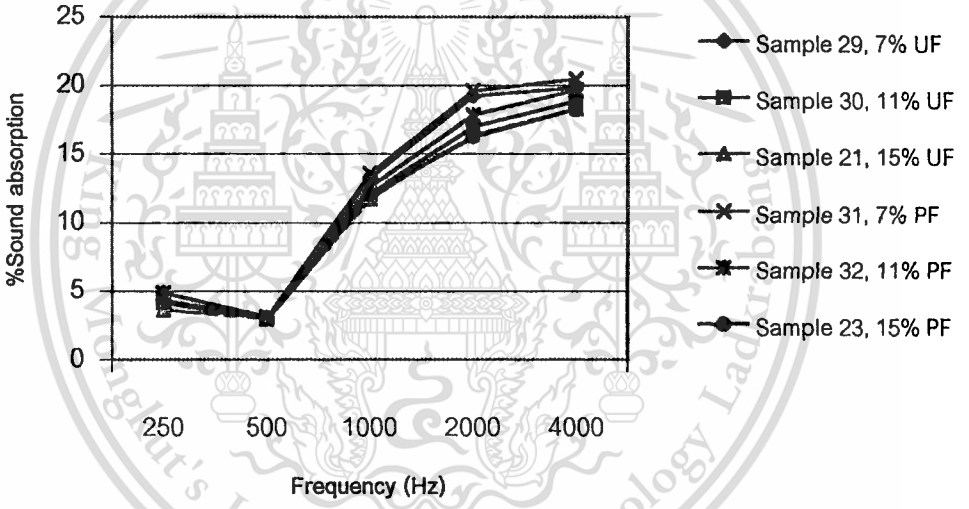


Figure 4.22 %Sound absorption vs frequency for various %adhesive of UF and PF

The effect of various adhesive quantities on sound absorption is shown in Figure 4.22. Graph shows that the boards with 7% of adhesive had highest sound absorption, whereas the boards with 15% of adhesive had lowest sound absorption as the proportions of adhesives were not sufficient to cover particle's surfaces of which their structure was porous. In general, the porous materials have good sound absorption properties [25] because such materials have open pore structures when sound wave passed through materials, air molecules are vibrated and forced through the pores and then interact with the pore wall, and frictional losses convert some of sound energy to heat energy [16,18].

PF boards have little higher sound absorption than UF boards. The reason described in 4.2.4.

In summary, particleboards which used 15% of adhesive, showed optimum properties except only sound absorption and nonslip-loosed edge. On the other hand, at 7% and 11% of adhesives showed poor slip-loosed edge which did not suitable for forming boards. So 15% of adhesives were chosen for further experiment.

4.6 Effect of Board Densities

To study effect of board densities, various board densities at 0.1, 0.3 and 0.6 g/cm^3 were prepared. Particleboards were formed by using BG/EPS ratio at 85/15 wt/wt, mixed size EPS, hot pressing at 100 °C for 10 minutes, 15% of UF and PF of dry particle weight as well as 20-35 mesh BG. The results are given in Table 4.6.

Table 4.6 Properties of particleboards with various boards densities

Properties	Samples					
	33	34	21	35	36	23
	0.1 g/cm^3 UF	0.3 g/cm^3 UF	0.6 g/cm^3 UF	0.1 g/cm^3 PF	0.3 g/cm^3 PF	0.6 g/cm^3 PF
Board density (g/cm^3)	0.11	0.33	0.62	0.12	0.33	0.61
Bending - **MOR** (MPa)	0.61	1.06	7.05	0.63	1.84	9.70
- **MOE** (MPa)	5.48	88.39	531.11	6.84	137.25	633.05
Water absorption 24 hrs (%)	382.2	161.6	73.3	318.9	141.9	48.0
Thickness swelling 24 hrs (%)	1.4	5.6	11.1	1.1	4.0	5.6
Sound absorption (%)						
250 Hz	2.23	4.77	3.63	2.09	5.22	4.11
500 Hz	1.93	3.81	2.87	1.83	4.08	3.02
1000 Hz	2.12	17.44	11.71	2.29	18.25	12.05
2000 Hz	4.66	19.08	16.41	4.97	19.65	16.26
4000 Hz	5.50	20.49	18.28	5.66	21.13	18.43
Thermal Conductivity (W/m K)	0.035	0.049	0.057	0.042	0.061	0.072

4.6.1 Water Absorption

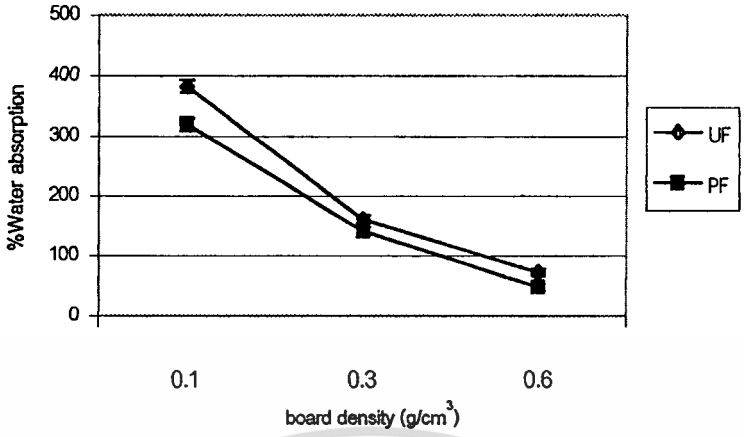


Figure 4.23 %Water absorption vs board densities

Figure 4.23 shows water absorption with various boards densities. It was found that boards density of 0.1 g/cm^3 provided the highest water absorption; in contrast, boards density of 0.6 g/cm^3 provided the lowest. There are noticeable that water absorption decreased by increasing boards densities. Because the pore sizes and numbers in low density boards were larger than those of high density boards. Hence, water absorption decreased when density increased.

With regard to water absorption, UF boards were higher than PF boards. The reason described in 4.2.1.

4.6.2 Thickness Swelling

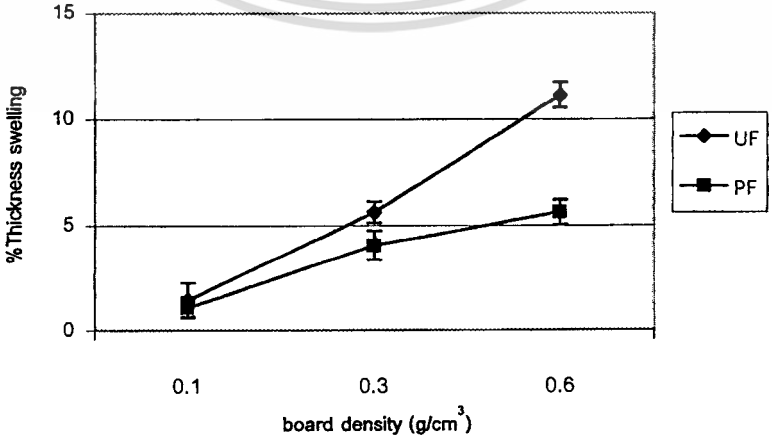


Figure 4.24 %Thickness swelling vs board densities

From the experimental results obtained (Figure 4.24), it is evident that thickness swelling increased by increasing boards densities. It is because after soaking, the particles released stress by springing back the compacted particles which were developed during pressing stage of boards preparation [29]. Therefore, the higher boards densities, the greater thickness swelling.

Thickness swelling of UF boards was higher than that of PF boards. As previously describe, thickness swelling is affected by bond qualities and adhesive properties [24]; thus, the weaker bond of UF boards showed the higher thickness swelling.

4.6.3 MOR and MOE

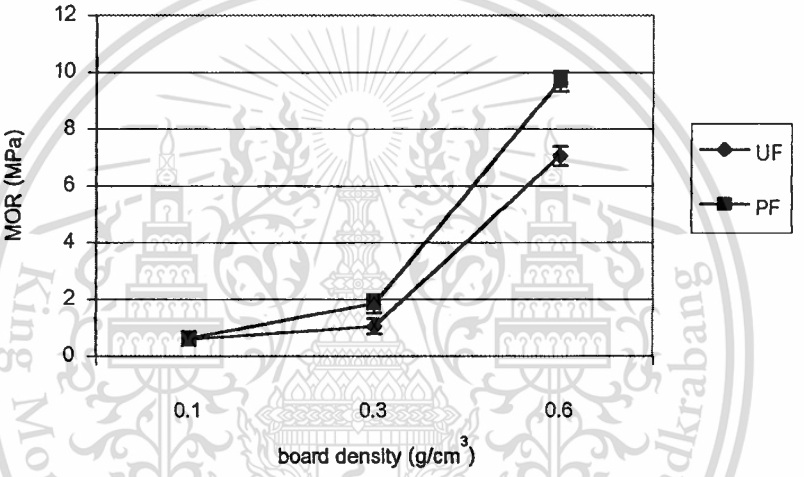


Figure 4.25 MOR (Modulus of Rupture) vs board densities

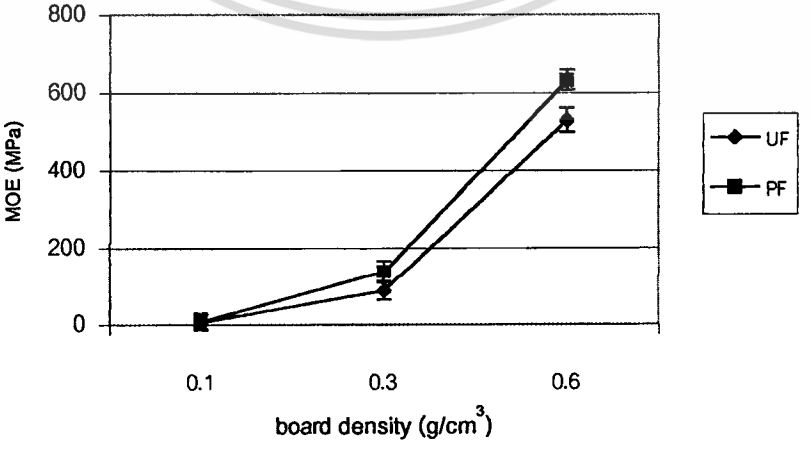


Figure 4.26 MOE (Modulus of Elasticity) vs board densities

Board density is a powerful factor affecting board properties. In most case, an increase in board density results in a concomitant improvement in physical properties [4]. As mentioned before, the increased board density resulted in more intimate contact between the particles in material being compressed into the final board. So when loading was applied, the high density boards were higher loading dissipation than the low density boards which showed in MOR and MOE (Figure 4.25 and 4.26).

The comparison of MOR and MOE between PF boards and UF boards showed that the first type of boards were higher MOR and MOE than the later type of boards. This is probably due to effect of the bonding strength of PF boards was higher than that of UF boards. Hence, they could absorb and well dissipate loading force.

4.6.4 Sound Absorption

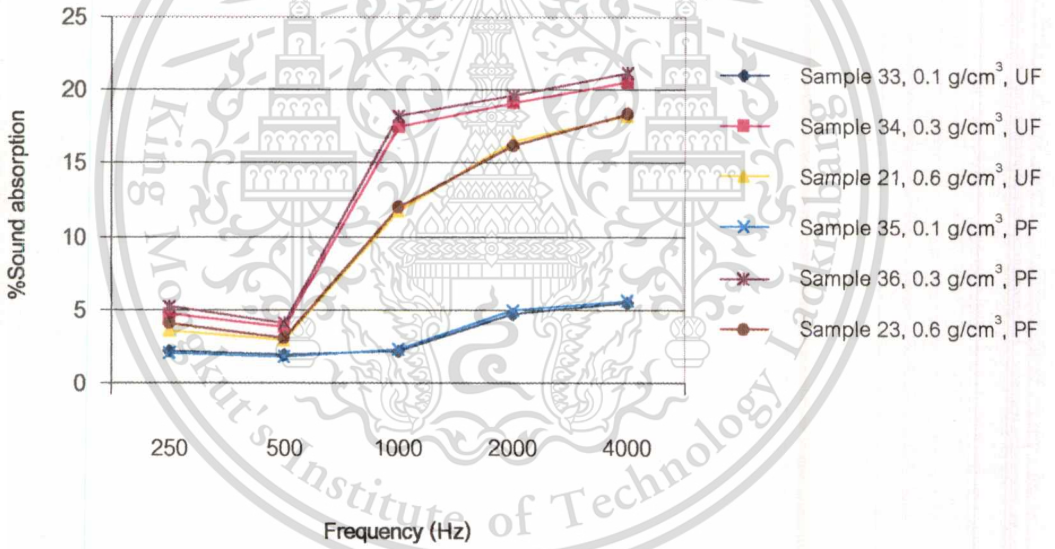


Figure 4.27 %Sound absorption vs frequency for various board densities

The effect of board densities on sound absorption is shown in Figure 4.27. The order of sound absorption from highest to lowest was 0.3, 0.6 and 0.1 g/cm^3. Consideration on mechanism of sound absorption occurs when the sound wave cause the air to vibrate down in the depths of porous materials, and frictional losses convert some of the sound energy to heat energy. The amount of loss is a function of the density or how tightly packed the particles are. If the particles are loosely packed, there is little frictional loss. If the particles are compressed into a dense board, there is little penetration and more reflection from the surface, resulting in less absorption [18].

So this is a reason why boards density of 0.3 g/cm^3 were higher sound absorption than the boards density of 0.6 g/cm^3. In contrast, boards density of 0.1 g/cm^3 were not according to above reason. This is probably because their cell geometry was likely to be an open-cell (tunnels between the cells) and thus sound wave could easily pass through the particleboards. Therefore, sound absorption of boards density of 0.1 g/cm^3 was lowest.

Under these experimental conditions, it was found that density of 0.3 g/cm^3 was the best density for sound absorption. There was no significant difference results between UF and PF boards at each density.

4.6.5 Thermal Conductivity

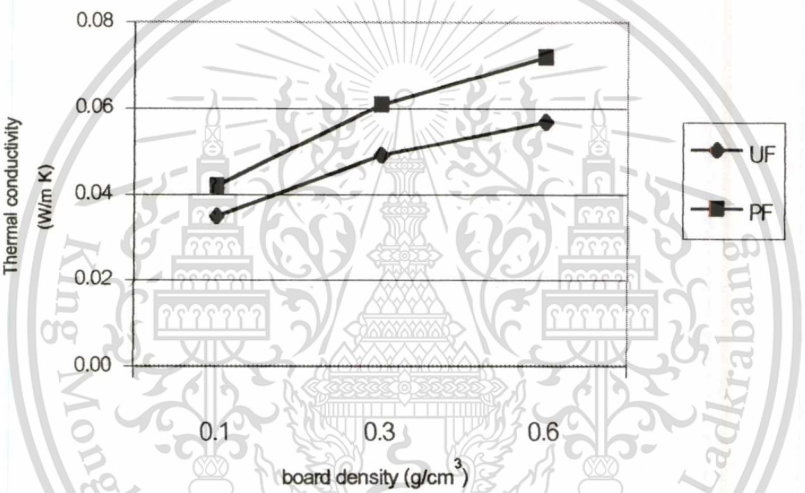


Figure 4.28 Thermal conductivity vs board densities

Thermal conductivity property of material is governed by many factors; one is their porosity. The materials should have a greater number of fine, closed and air-filled pores [19]. Air-phase has rather lower thermal conductivity (0.02423 W/m K at 0 °C and 0.03185 W/m K at 100 °C [15]) than solid-phase. Hence, the greater number of pores, the lower thermal conductivity. As above mentioned, there are supported to this experimental results that thermal conductivity decreased by decreasing board densities (Figure 4.28). Because the lower density boards, the higher number of pores.

In summary, 0.1 g/cm^3 density boards showed low thickness swelling and thermal conductivity but they were easy break. Board density 0.3 g/cm^3 showed good sound absorption

and fairly thermal conductivity. Finally 0.6 g/cm^3 density boards provided low water absorption and high bending strength. This is because, this study focused on sound absorption and thermal insulation properties, so the suitable density should be 0.3 g/cm^3.

4.6.6 Morphological Study by SEM

SEM studied the morphology of boards especially on their porosities. The interested board densities in this study were 0.1, 0.3 and 0.6 g/cm^3 which were formed by using 15% of UF and PF of dry particle weight, BG/EPS ratio at 85/15 wt/wt, mixed size EPS and BG of 20-35 mesh. The small pieces of particleboards were fractured at low temperature by dipping in liquid nitrogen. After that the fractured boards were magnified at 10 time by SEM. SEM micrographs are shown in Figure 4.29. There are evident that the lower density boards were less contact between the particles than the higher density boards and thus boards were rather greater pores.

Comparison of SEM micrographs between UF boards and PF boards found that there were no any significant difference. Both of their porosities and particles arrangements were similar.

SEM micrographs supported that the closely contact particles resulted in the boards less porosities thus led to less water absorption and high bending strength which evaluated from MOR and MOE. In addition, thickness swelling of high density boards was high after soaking, due to the compacted particles released their stress. For sound absorption properties, the tightly packed particles had less sound absorption. It is because sound waves had little penetration and more reflection from surfaces resulting in less absorption. Finally, for thermal conductivity of high density boards were high since they were less pores inside, and there were vice versa in low density boards.

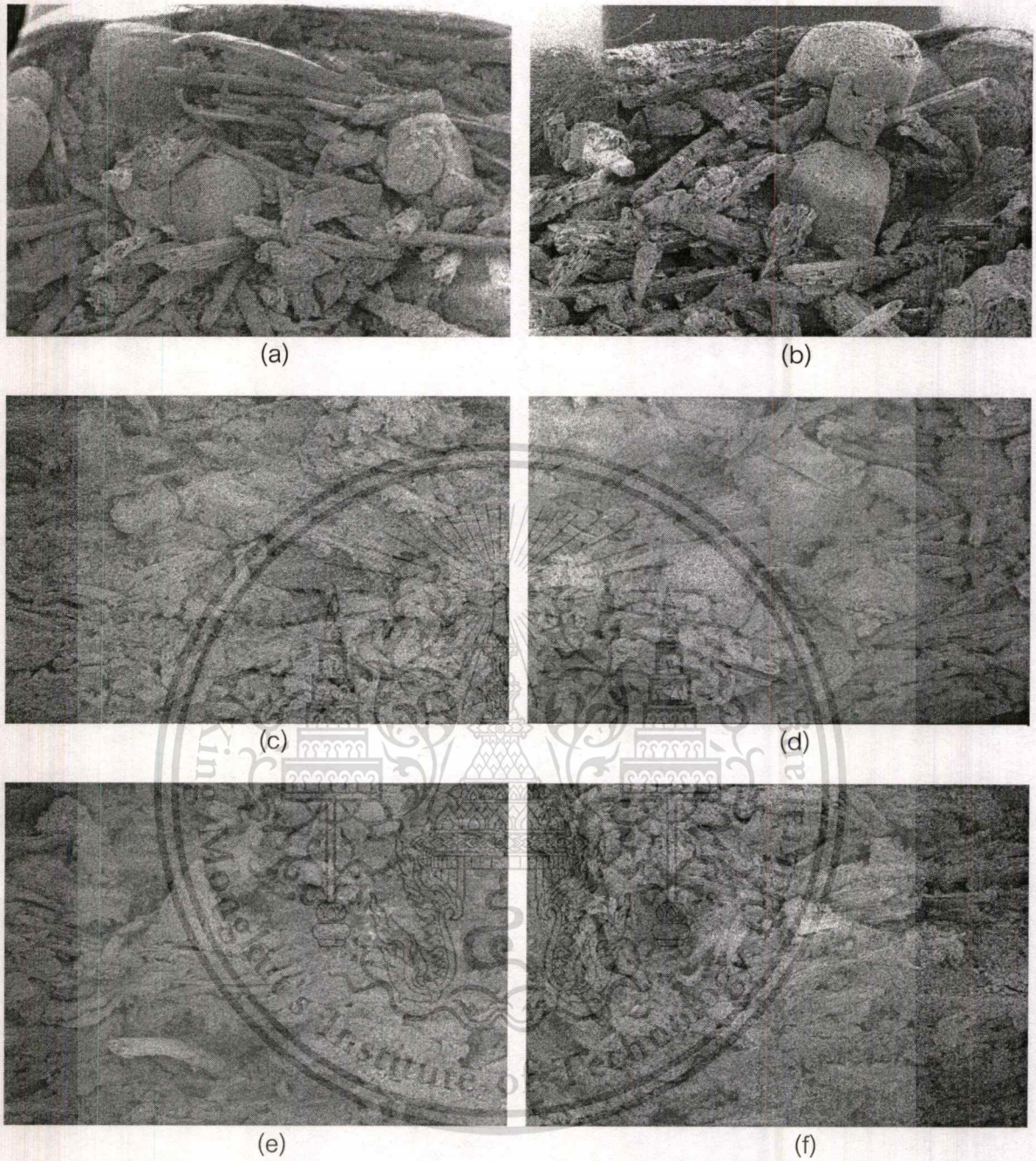


Figure 4.29 SEM micrographs of particleboards (x10)

(a) Density = 0.1 g/cm^3 , UF (Sample 33) (b) Density = 0.1 g/cm^3 , PF (Sample 35)

(c) Density = 0.3 g/cm^3 , UF (Sample 34) (d) Density = 0.3 g/cm^3 , PF (Sample 36)

(e) Density = 0.6 g/cm^3 , UF (Sample 21) (f) Density = 0.6 g/cm^3 , PF (Sample 23)

4.7 Effect of Presence and Absence of EPS

Presence and absence of EPS in particleboards were studied. Factors to be involved included 100% of BG, BG/EPS ratio at 85/15 wt/wt, mixed size EPS, 15% of UF and PF of dry particle weight, 20-35 mesh BG, hot pressing at 100 °C for 10 minutes. The target board densities were 0.3 g/cm^3 and 0.6 g/cm^3. The results are given in Table 4.7.

Table 4.7 Properties of presence and absence of EPS particleboards

Properties	Samples							
	37	34	38	36	39	21	40	23
	Absence EPS, UF	Presence EPS, UF	Absence EPS, PF	Presence EPS, PF	Absence EPS, UF	Presence EPS, UF	Absence EPS, PF	Presence EPS, PF
Board density (g/cm^3)	0.32	0.33	0.33	0.33	0.59	0.62	0.63	0.61
Bending								
- **MOR** (MPa)	0.74	1.06	1.32	1.84	4.95	7.05	6.23	9.70
- **MOE** (MPa)	51.99	88.39	107.13	137.25	445.93	531.11	513.42	633.05
Water absorption 24 hrs (%)	209.5	161.6	187.1	141.9	115.8	73.3	90.3	48.0
Thickness swelling 24 hrs (%)	8.8	5.6	7.5	4.0	16.9	11.1	12.6	5.6
Sound absorption (%)								
250 Hz	4.31	4.77	4.99	5.22	3.25	3.63	3.72	4.11
500 Hz	4.00	3.81	4.75	4.08	2.92	2.87	3.40	3.02
1000 Hz	11.58	17.44	11.68	18.25	11.41	11.71	11.58	12.05
2000 Hz	11.90	19.08	12.09	19.65	15.93	16.41	15.86	16.26
4000 Hz	12.50	20.49	12.55	21.13	17.77	18.28	18.01	18.43

4.7.1 Water Absorption

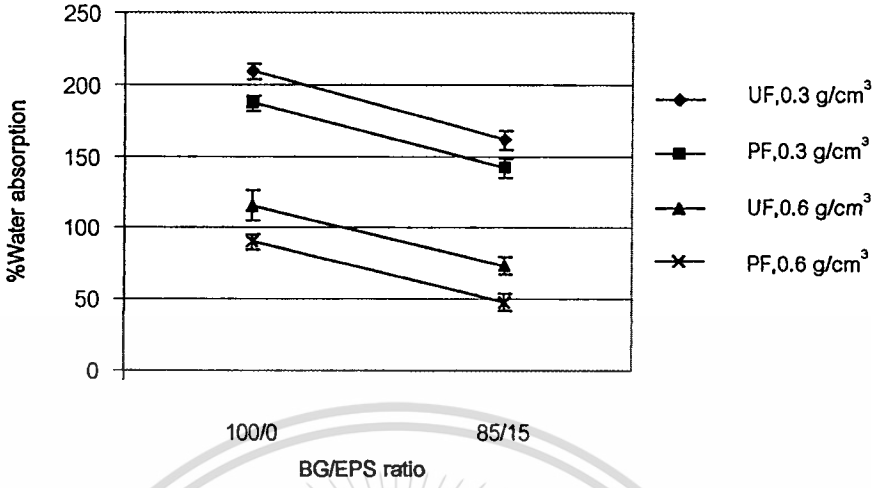


Figure 4.30 %Water absorption vs BG/EPS ratios (presence and absence of EPS)

The effect of 0.3 g/cm^3 and 0.6 g/cm^3 at the presence and absence of EPS of boards on water absorption found that (Figure 4.30) absence of EPS of boards were higher water absorption than presence of EPS of boards. Since BG are cellulose which composed of hydroxy groups. Normally, hydroxy groups can easily absorb water; in contrast, EPS is a hydrocarbon polymer which could not absorb water. Therefore absence of EPS of boards showed higher water absorption.

With regard to water absorption, UF boards were higher than PF boards. The reason described in 4.2.1.

The experiment found that the higher density boards, the lower water absorption. Since the higher density boards were lower pores than the lower density boards.

4.7.2 Thickness Swelling

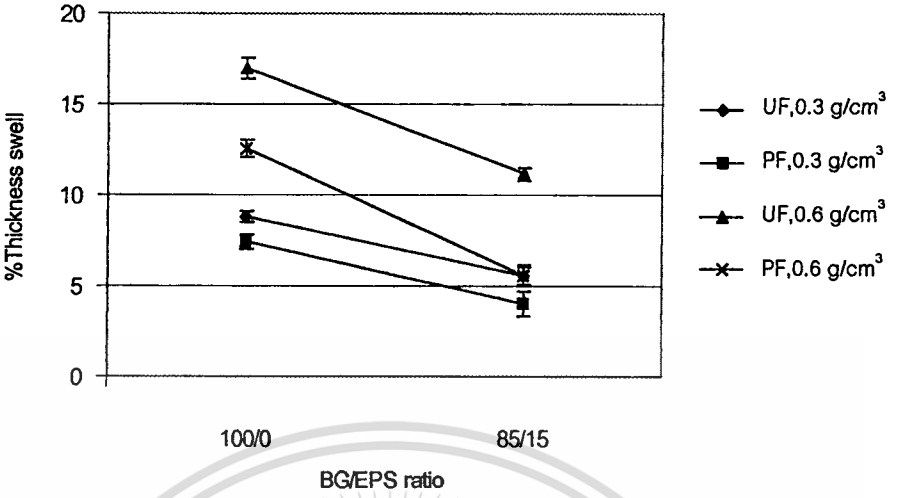


Figure 4.31 %Thickness swelling vs BG/EPS ratios (presence and absence of EPS)

Figure 4.31 shows thickness swelling with 0.3 and 0.6 g/cm^3 with the presence and absence of EPS of boards. It can be seen that the absence of EPS of boards caused higher thickness swelling than the presence of EPS of boards as cellulose of BG are easily absorb water.

Thickness swelling of UF boards was higher than that of PF boards. As previously described, thickness swelling is affected by bond qualities and adhesive properties [24]; thus, the weaker bond of UF boards, the higher thickness swelling.

4.7.3 MOR and MOE

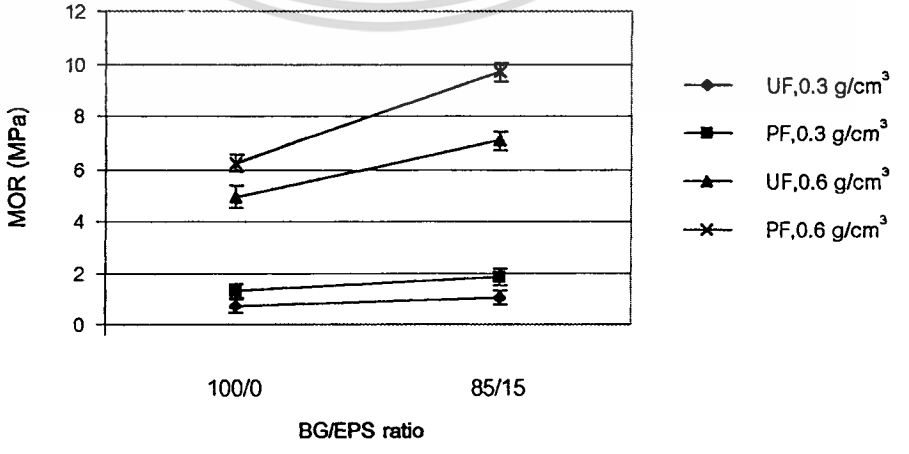


Figure 4.32 MOR (Modulus of Rupture) vs BG/EPS ratios (presence and absence of EPS)

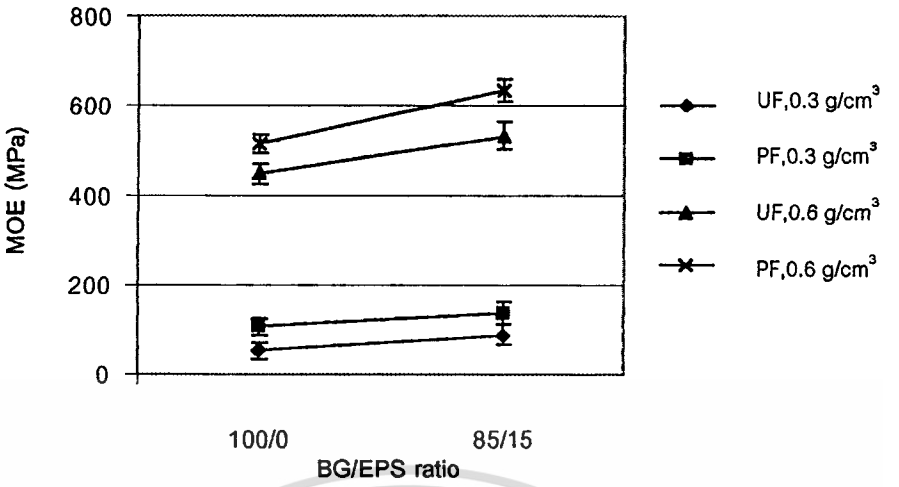


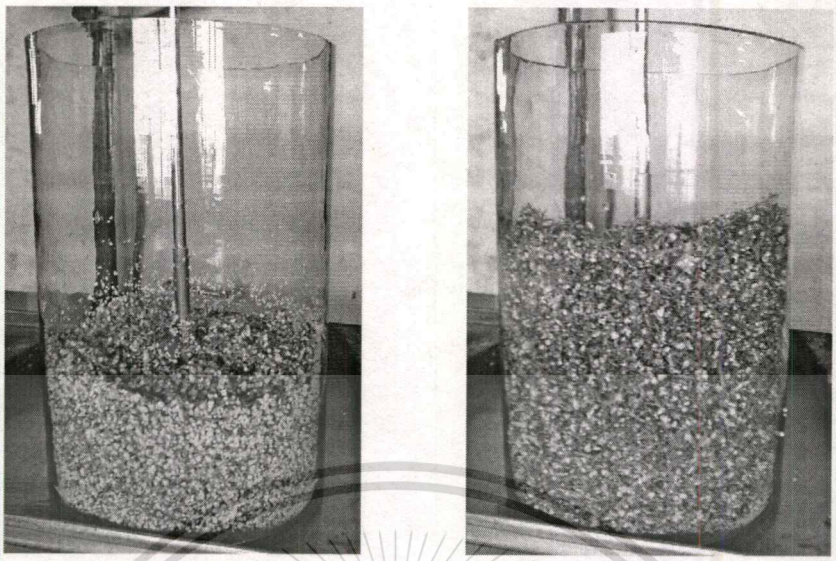
Figure 4.33 MOE (Modulus of Elasticity) vs BG/EPS ratios (presence and absence of EPS)

MOR of 0.3 and 0.6 g/cm^3 at the presence and absence of EPS of boards are shown in Figure 4.32. The presence of EPS of boards had rather higher MOR than the absence of EPS of boards. This is probably because the dispersion of adhesives showed well with the presence of EPS. Additionally EPS is a nonpolar polymer, it then led to occur electrostatic in the mixture. Such electrostatic caused by rubbing between EPS and BG during the blending process. As a result, the mixture became fluffy as shown in Figure 4.34. In opposite, this incident did not exist in 100% of BG (at the absence of EPS) as shown in Figure 4.35. The fluff resulted in less agglomerating BG with adhesives. Consequently, MOR at the presence of EPS of boards showed higher than that of the absence of EPS of boards.

The comparison of MOR between PF boards and UF boards showed that the first type of boards had higher MOR than the later type of boards. This is probably because bonding strength of PF boards was higher than that of UF boards. Hence, they could absorb and well dissipate loading force.

It is observed that MOR of 0.6 g/cm^3 boards was higher than that of 0.3 g/cm^3 boards since high density boards had more contact between particles. So when loading was applied, they were higher loading dissipation and vice versa in low density boards.

Figure 4.33 shows MOE of 0.3 and 0.6 g/cm^3 at the presence and absence of EPS of boards. MOE showed a similar trend as MOR.



(a) (b)

Figure 4.34 Illustrate the mixture of BG and EPS in blending container

(a) before stirring and adding adhesive , (b) after stirring and adding adhesive

(a) (b)

Figure 4.35 Illustrate BG in blending container

(a) before stirring and adding adhesive , (b) after stirring and adding adhesive

4.7.4 Sound Absorption

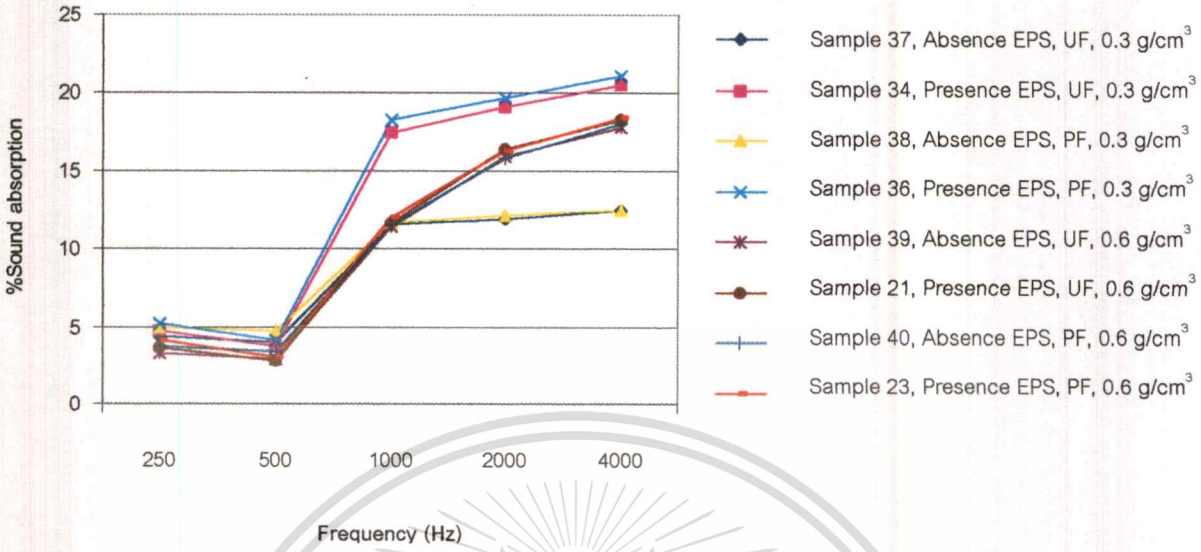


Figure 4.36 %Sound absorption vs frequency for various BG/EPS ratios (presence and absence of EPS)

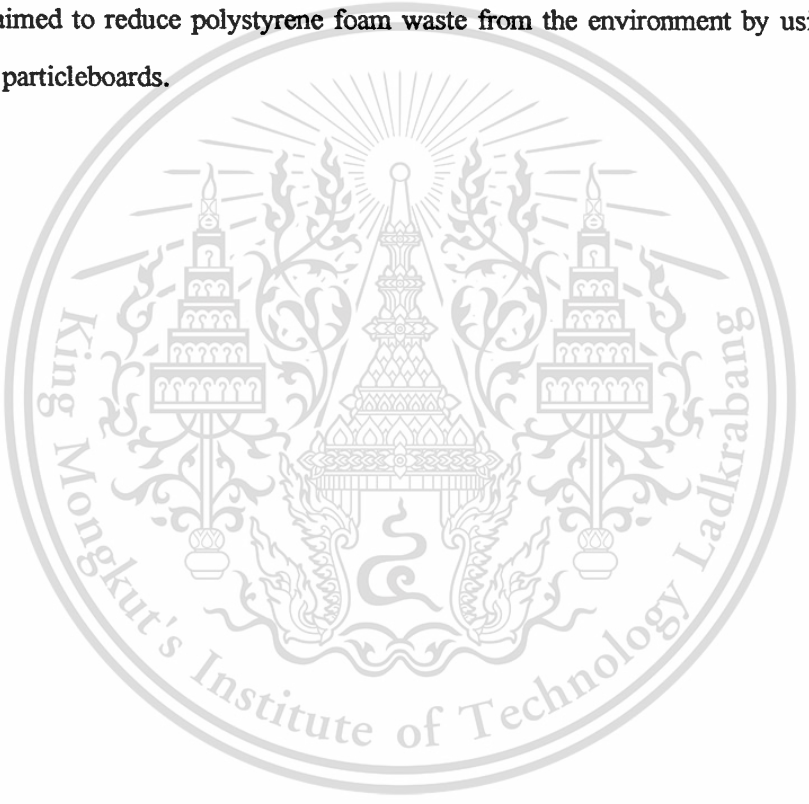
Comparison of the results of sound absorption between presence and absence of EPS of boards are shown in Figure 4.36. First, when considering 0.3 g/cm^3 density boards, sound absorption of the presence of EPS of boards was higher than that of the absence of EPS of boards. It is because EPS structure had porosity so it had a good sound absorption property. When considering 0.6 g/cm^3 density boards, boards with the presence of EPS, they had little higher sound absorption than at the absence of EPS of boards. It is because porosities of EPS were greater reduced because of compressing stage; hence, BG and EPS became closely contact. Therefore, they were not significantly different in sound absorption.

PF boards had little higher sound absorption than UF boards. The reason described in 4.2.4.

Comparison of the results of sound absorption between 0.3 g/cm^3 and 0.6 g/cm^3 density boards which were formed by 100% BG (at the absence of EPS) indicated that the high density boards had higher sound absorption than the low density boards. This results were contrast to [18] said that the higher density boards, the lower sound absorption. This is probably because bonding strength of the low density boards was quite rather low and thus particles appear relaxation losses due to the deformation of their compositions when sound wave passed. Hence, sound wave intensity less decreased which was evaluated by sound absorption.

Finally, comparison of the results of sound absorption between 0.3 g/cm^3 and 0.6 g/cm^3 density boards which were formed by BG/EPS ratio at 85/15 wt/wt indicated that sound absorption of low density boards was higher than that of high density boards. Because particles of low density boards were loosely packed, there were little frictional loss, while particles of high density boards were compressed into a dense boards, there were little penetration and more reflection from the surfaces, resulting in less sound absorption.

In summary, particleboards which consisted of EPS, showed better properties than particleboards which did not consist of EPS. So those results supported the objectives of this study which aimed to reduce polystyrene foam waste from the environment by using as a one component in particleboards.



4.8 Effect of Bagasses Sizes

The effect of BG sizes on water absorption, thickness swelling, MOR and MOE as well as sound absorption were studied. Two types of boards were formed from 20-35 mesh BG and less than 20 mesh BG. Moreover, they were composed of BG/EPS ratio at 85/15 wt/wt, mixed size EPS, 15% of UF and PF of dry particle weight, hot pressing at 100 °C for 10 minutes. The target board density was at 0.3 g/cm^3. The results are given in Table 4.8.

Table 4.8 Properties of particleboards with various BG sizes

Properties	Samples			
	34	41	36	42
	BG 20-35 mesh, UF	BG less than 20 mesh, PF	BG 20-35 mesh, UF	BG less than 20 mesh, PF
Board density (g/cm^3)	0.33	0.31	0.33	0.31
Bending - MOR (MPa)	1.06	2.07	1.84	2.92
- MOE (MPa)	88.39	137.10	137.25	196.94
Water absorption 24 hrs (%)	161.6	150.8	141.9	132.7
Thickness swelling 24 hrs (%)	5.6	5.0	4.0	3.8
Sound absorption (%)				
250 Hz	4.77	3.80	5.22	3.86
500 Hz	3.81	3.01	4.08	3.63
1000 Hz	17.44	16.81	18.25	17.02
2000 Hz	19.08	18.97	19.65	19.07
4000 Hz	20.49	20.42	21.13	21.30

4.8.1 Water Absorption

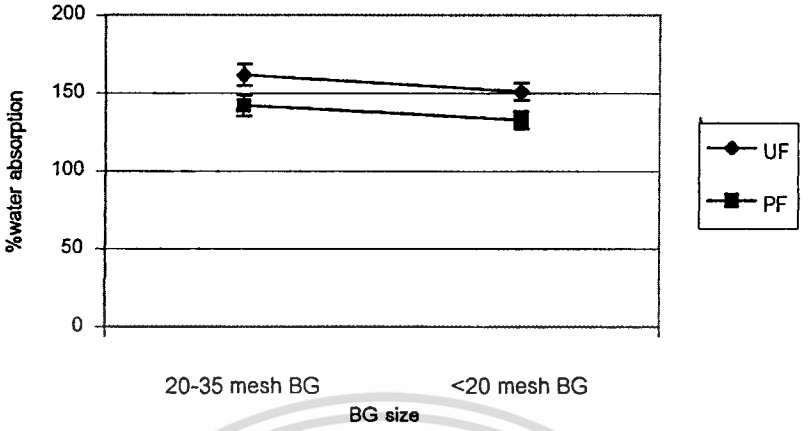


Figure 4.37 %Water absorption vs BG sizes

Water absorption of boards with BG of 20-35 mesh was slightly higher than that of boards with BG of less than 20 mesh (Figure 4.37). Because BG of 20-35 mesh were less in shape so they were great in surface area. Consequently, their water absorption should be higher than BG of less than 20 mesh.

With regard to water absorption, UF boards were higher than PF boards. The reason described in 4.2.1.

4.8.2 Thickness Swelling

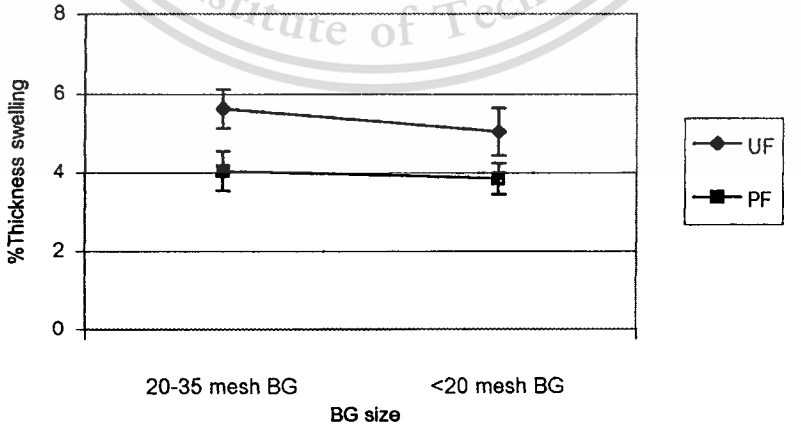


Figure 4.38 %Thickness swelling vs BG sizes

Figure 4.38 shows thickness swelling of different BG sizes. It can be seen that the boards with BG of 20-35 mesh were little higher thickness swelling than the boards with BG of less than 20 mesh. Normally, thickness swelling shows a similar trend as water absorption. Therefore, the higher water absorption, the greater thickness swelling.

4.8.3 MOR and MOE

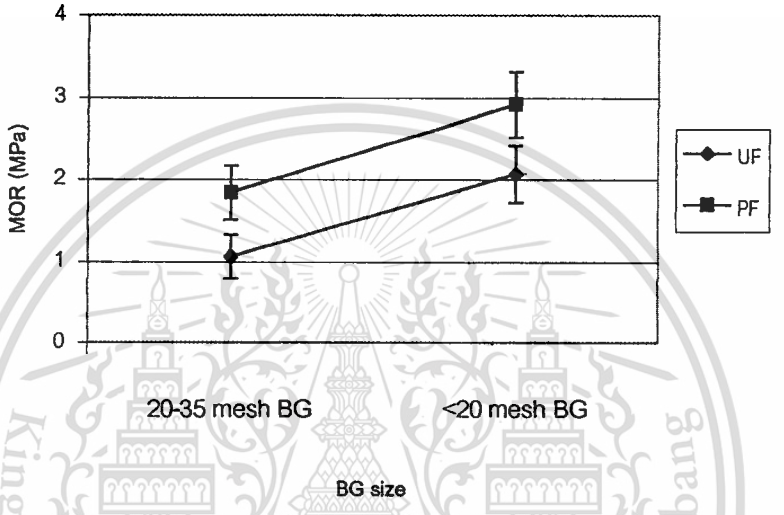


Figure 4.39 MOR (Modulus of Rupture) vs BG sizes

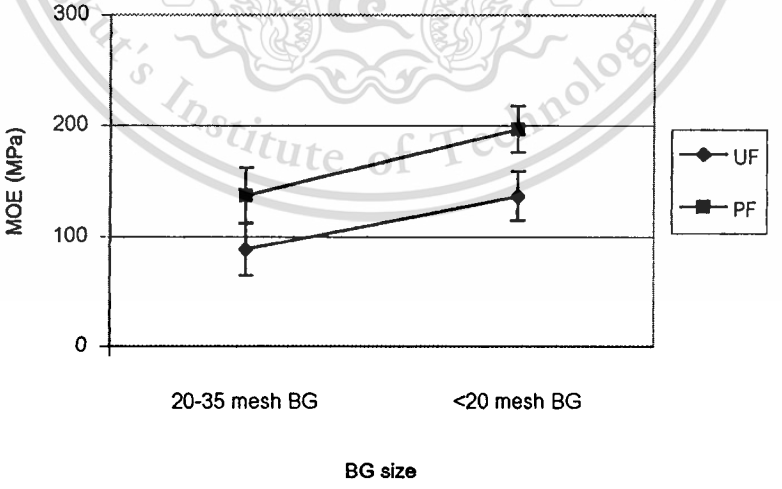


Figure 4.40 MOE (Modulus of Elasticity) vs BG sizes

In fact, the greater aspect ratio of materials shows higher strength. The experimental results indicated that the aspect ratio of BG of less than 20 mesh was higher than the aspect ratio of BG

of 20-35 mesh. For this reason, MOR of boards with BG of less than 20 mesh was higher than boards with BG of 20-35 mesh as shown in Figure 4.39.

The comparison of MOR between PF boards and UF boards showed that the first type of boards had higher MOR than the latter type of boards. This is probably because bond strength of PF boards was higher than that of UF boards. Hence, they could absorb and well dissipate loading force.

MOE of two BG sizes showed a similar trend as MOR which is shown in Figure 4.40. The results show that MOE increased by increasing BG sizes. Besides, MOE of PF boards was higher than that of UF boards.

4.8.4 Sound Absorption

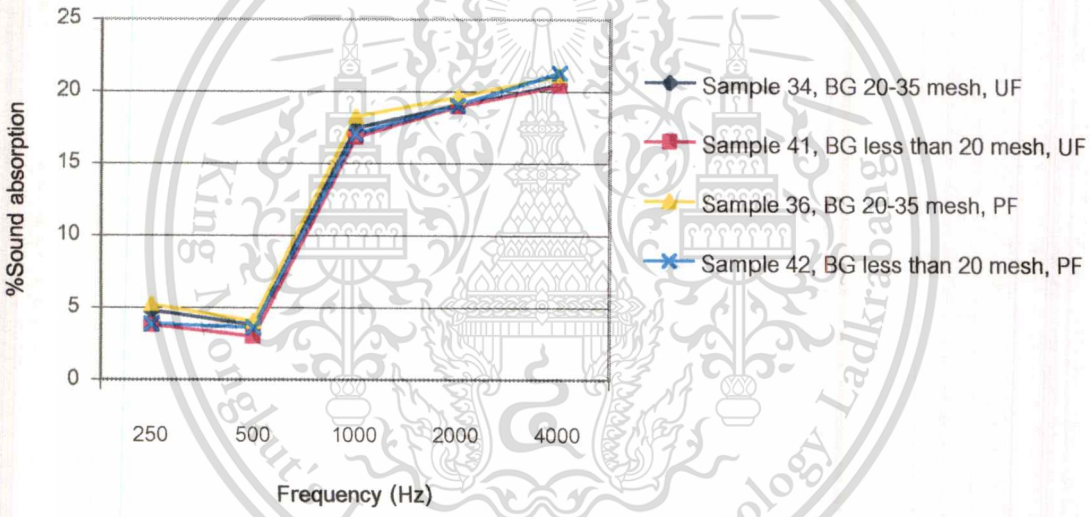


Figure 4.41 %Sound absorption vs frequency for various BG sizes

The effect of BG sizes on sound absorption is shown in Figure 4.41. The graph indicated that sound absorption of both types of boards were nearly the same. There were probably of the same density.

PF boards had little higher sound absorption than UF boards. The reason described in 4.2.4.

In summary, particleboards which formed of BG of less than 20 mesh, showed bending strength, water absorption resistance and thickness swelling resistance better than BG of 20-35 mesh. With the exception of sound absorption, they were nearly the same. BG of 20-35 mesh

produced fineness and smoothness board surfaces while BG of less than 20 mesh gave coarseness board surfaces. So BG of 20-35 mesh was suitable in this study.

4.9 Comparison with International Standard Specification

The experimental results suggested that the boards with 0.3 g/cm^3 density of UF (sample 34) and PF (sample 36) showed significantly in sound absorption and thermal insulation property. Whereas the boards with 0.6 g/cm^3 density of UF (sample 21) and PF (sample 23) showed significantly in mechanical property and water absorption resistance. Hence, the proper formula must be chosen according to the application requirement.

Table 4.9 shows the comparison of properties for those 4 formulae with international standard specification and general commercial gypsum board (one brand in Thailand). Figure 4.42-4.47 present comparison of those 4 formulae with general commercial gypsum board.

Table 4.9 Properties comparison of experimental particleboards with international standard specification and general commercial gypsum board

Properties	International Standard Specification of Particleboard [1]				International Standard Specification of Medium Density Fiberboard [2]	Gypsum board[3]	Samples (this study)			
	TIS 876-2532	ANSI A208.1 1993 type M-S	BS 5669: 1979	JIS A 5908. 1994 type 13	ANSI A208.2 1994		Sample 34 (0.3 g/cm^3,UF)	Sample 36 (0.3 g/cm^3,PF)	Sample 21 (0.6 g/cm^3,UF)	Sample 23 (0.6 g/cm^3,PF)
Board density (g/cm^3)	NS[4]	NS	NS	NS	0.64-0.80	0.68	0.33	0.33	0.62	0.61
MOR (MPa)	13.8	12.5	13.8	13	24	3.09	1.06	1.84	7.05	9.7
MOE (MPa)	2,000	1,900	2,000	2,500	2,400	269.37	88.39	137.25	531.11	633.05
Water absorption 24 hrs (%)	80	NS	NS	NS	NS	51.5	161.6	141.9	73.3	48.0
Thickness swelling 24 hrs (%)	12 (1 hr)	NS	12 (1 hr)	12	NS	2.3	5.6	4.0	11.1	5.6
Sound absorption (%)										
250 Hz	NS	NS	NS	NS	NS	4.07	4.77	5.22	3.63	4.11
500 Hz	NS	NS	NS	NS	NS	2.72	3.81	4.08	2.87	3.02
1000 Hz	NS	NS	NS	NS	NS	11.45	17.44	18.25	11.71	12.05
2000 Hz	NS	NS	NS	NS	NS	15.12	19.08	19.65	16.41	16.26
4000 Hz	NS	NS	NS	NS	NS	16.76	20.49	21.13	18.28	18.43
Thermal Conductivity (W/m K)	NS	NS	NS	NS	NS	0.191[5]	0.049	0.061	0.057	0072

Remark:

(1) Standard name [28]
- TIS 876-2532 (Thailand) = Standard For Flat Pressed Particleboards : Medium Density
- ANSI A208.1 1993 (USA) = Standard For Mat Formed Wood Particleboard
- BS 5669: 1979 (British) = Specification For Wood Chipboard and Test Methods for Particleboard
- JIS A 5908. 1994 (Japan) = Particleboards

(2) ANSI A208.2 1994 = American National Standard for MDF

(3) General commercial gypsum board one brand in Thailand.

(4) NS = Not Specified

(5) Board density 0.88 g/cm^3 [3]

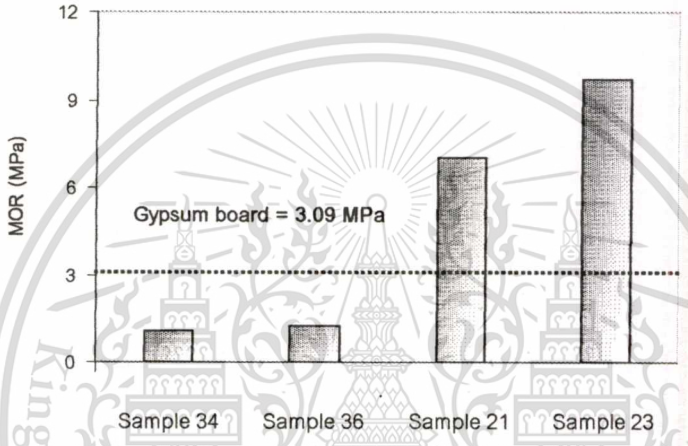


Figure 4.42 Comparison MOR (Modulus of Rupture) of experimented particleboards with general commercial gypsum board

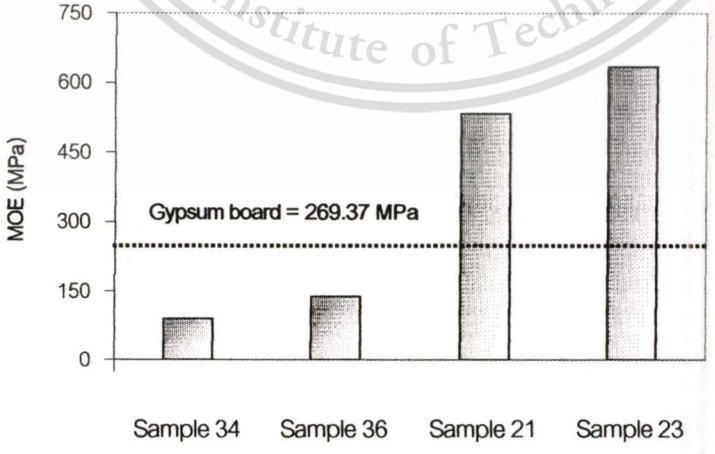


Figure 4.43 Comparison MOE (Modulus of Elasticity) of experimented particleboards with general commercial gypsum board

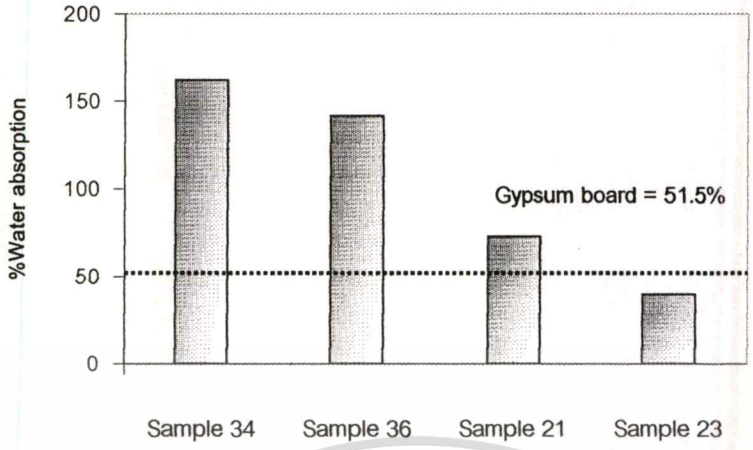


Figure 4.44 Comparison water absorption of experimented particleboards with general commercial gypsum board

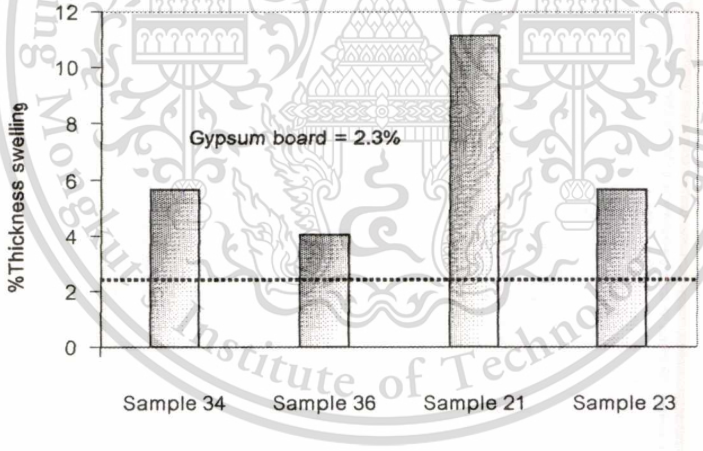


Figure 4.45 Comparison thickness swelling of experimented particleboards with general commercial gypsum board

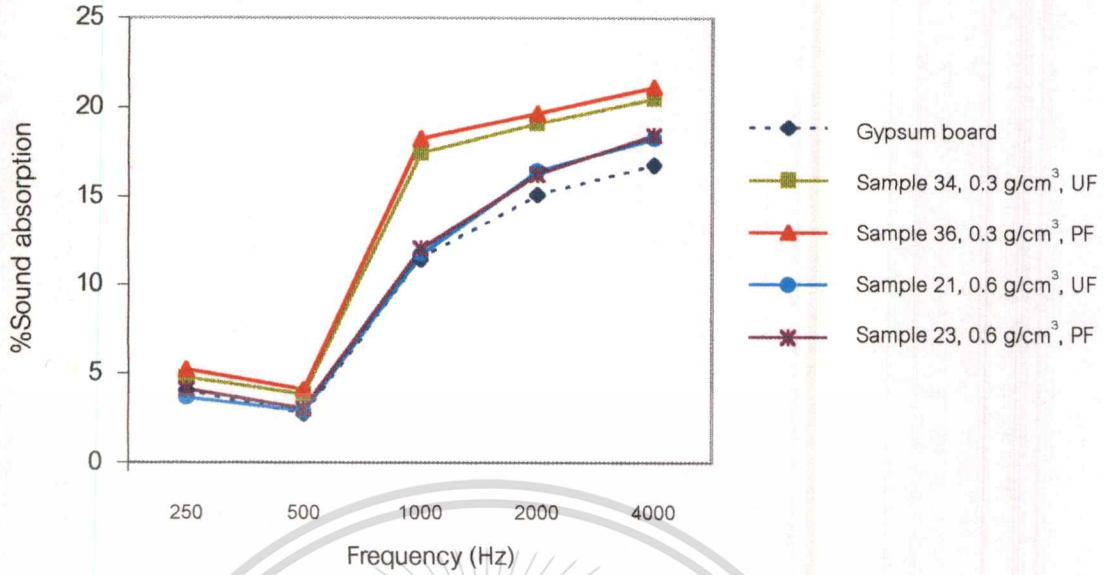


Figure 4.46 Comparison sound absorption of experimented particleboards with general commercial gypsum board

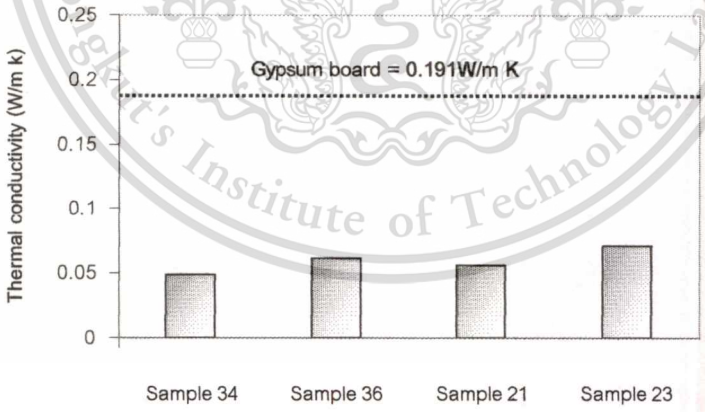


Figure 4.47 Comparison thermal conductivity of experimented particleboards with general commercial gypsum board

Although the 0.3 g/cm^3 density boards yield unsatisfactory results of mechanical properties and water absorption resistance, they showed significantly in sound absorption property and thermal insulation property. Thus it was suitable for sound absorption application and thermal insulation. There are two possible methods to improve mechanical property and water absorption resistance of particleboards. The first method is by changing the blending machine. Normally the commercial blending machine will apply adhesives into the particles as atomized resin (means vary fine drops of resin) by using spray nozzle, resulting in uniform distribution of resins. However, for this experiment the adhesives were applied by gradually dropping into the particles, leading to poor distribution of resins. Moreover, MOR decreased at the increase of the average sizes of atomized resins [28]. If the average sizes of atomized resins are very fine, MOR will increase. Second method is adding wax. The commercial boards usually add wax in order to improve resistance of water absorption while this experiment were lack of this process.

In case of 0.6 g/cm^3 density boards, thermal insulation property was lower than that of general commercial gypsum board. Also, sound absorption was higher than that of general commercial gypsum board. Moreover, they were slightly higher than those of general commercial gypsum board if compared to the 0.3 g/cm^3 density boards. Water absorption resistance and thickness swelling were in range of international standard specification. These typical boards showed significantly in mechanical properties when compared to general commercial gypsum board, thus they were suitable for strength application.

The illustration of experimental particleboards : sample 34, 36, 37, 38, 41 and 42 are shown in Figure 4.48.

Figure 4.48 Illustrate the experimental particleboards (14 cm x 16 cm)

Left top : sample 37, 100%BG, BG 20-35 mesh, UF, density 0.3 g/cm^3

Right top : sample 38, 100%BG, BG 20-35 mesh, PF, density 0.3 g/cm^3

Left middle : sample 34, BG/EPS = 85/15, BG 20-35 mesh, UF, density 0.3 g/cm^3

Right middle : sample 36, BG/EPS = 85/15, BG 20-35 mesh, PF, density 0.3 g/cm^3

Left bottom : sample 41, BG/EPS = 85/15, BG less than 20 mesh, UF, density 0.3 g/cm^3

Right bottom : sample 42, BG/EPS = 85/15, BG less than 20 mesh, PF, density 0.3 g/cm^3

CHAPTER 5

CONCLUSIONS

5.1 Conclusions

This thesis studied on the preparation of particleboards from bagasses (BG) and expanded polystyrene foam (EPS) waste. The study focused on investigation of their properties particularly on the sound absorption and thermal insulation areas. Additionally, others properties were also investigated, i.e. mechanical properties (MOR and MOE) and physical properties (water absorption and thickness swelling). Several parameters involved in the preparation process. There were eight procedures to prepare the boards.

First, found the quantity of urea-formaldehyde (UF) and phenol-formaldehyde (PF). The appropriate quantity was set at 15% of dry particle weight. Second, found the ratio between BG and EPS. BG/EPS at 85/15 wt/wt was considered the right one. Third, found the size of EPS. EPS mixed size was reasonable. Fourth, come up with the curing time. The suitable curing time was at 10 minutes. Fifth, found the optimum UF and PF quantity again. At 15% of dry particle weight was still optimum quantity. Sixth, found the board density. At 0.3 g/cm^3 density was the best for this thesis objectives. Seventh, studied the effect of the presence and absence of EPS in board in supporting the objectives of this thesis, that is, to reduce polystyrene foam waste in the environment by using it as a one component in board preparation. We found that the presence of EPS was better than the absence of EPS in board. Finally, the effect of BG size on board properties was examined. The suitable size was 20-35 mesh.

The comparison of properties between two types of adhesives, UF and PF. It was found that PF boards had better water absorption resistance, thickness swelling resistance, bending strength and sound absorption than UF boards. While UF boards had only better thermal insulation property than PF boards.

The experiment showed that the suitable particleboards for using as a sound absorption and thermal insulation material (compared with general commercial gypsum board) were produced from the above procedures. In case of sound absorption, particleboard should prepared at 0.3 g/cm^3 density from BG of 20-35 mesh, EPS mixed size, BG/EPS ratio at 85/15 wt/wt, hot pressing at 100 °C for 10 minutes and used PF at 15% of dry particle weight. Whereas UF 15% of dry particle weight was suitable for preparing thermal insulation particleboard. The properties of

such boards are as follows, in case that PF was used; percentage of sound absorption were 5.22, 4.08, 18.25, 19.65 and 21.13 at 250, 500, 1000, 2000 and 4000 Hz respectively. Thermal conductivity was 0.061 W/m K, MOR was 1.84 MPa, MOE was 137.25 MPa, percentage of water absorption was 141.9 and percentage of thickness swelling was 4.0. In case of UF used, percentage of sound absorption were 4.77, 3.81, 17.44, 19.08 and 20.49 at 250, 500, 1000, 2000 and 4000 Hz respectively, thermal conductivity was 0.049 W/m K, MOR was 1.06 MPa, MOE was 88.39 MPa, percentage of water absorption was 161.6 and percentage of thickness swelling was 5.6.

It can be concluded from this experiment that :

1. Water absorption and thickness swelling decreased when the amount of BG decreased. What to be increased were time of curing, adhesive quantity, board density (except in thickness swelling property), BG size and the presence of EPS in board.

2. Bending strength increased in parallel with increasing amount of EPS, time of curing, adhesive quantity, board density, BG size and with the presence of EPS in board.

3. Sound absorption increased at the increase of time of curing, board density at 0.3 g/cm^3 and with the presence of EPS in board.

4. Thermal conductivity decreased at the decrease of board density.

5. EPS foam consisted in particleboards helped improve such properties as water absorption, thickness swelling, MOR, MOE and sound absorption.

In summary, it is possible to prepare proper particleboards from the mixture of bagasses and expanded polystyrene foam waste by selecting compositions and conditions. Additionally, this new type of particleboards was suitable for making use of agriculture wastes and expanded polystyrene foam waste.

5.2 Suggestion for Furture Work

The properties of the studied particleboards are still not superior. Therefore, further research should be conducted as follows.

1. Using blending machine which has spray nozzle in order to produce atomized resin (means very fine drops of resin) which may improve bending strength and reduce adhesive quantity as well.

2. Addition with wax may be used to improve resistance to water absorption.

3. Modification with alkaline in lignocellulosic materials may be used to improve bending strength.

4. Finishing surface e.g. vinyl coating, paper covering tends to be necessary to enhance long duration and attractive features.

5. The test of sound absorption should be conducted under the standard testing method in order to receive sound absorption coefficient (a). Moreover, this received data could compare our studied data with standard specification.

6. The method of testing sound properties should focus on sound reflection together with sound absorption in order to provide accurate results.

7. Moisture content of test pieces should be strictly controlled before testing thermal conductivity.

5.3 Applications

1. Ceiling tile or wall for reducing sound and heat.

2. Furniture part e.g. arms of chair, cover part at backside and etc.

3. General purposes e.g. picture frame, loud speaker box, decorative part and etc.

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APPENDIX

APPENDIX A Properties of Particleboards

Table A.1 Mechanical and physical properties of particleboards and general commercial gypsum board

Samples	M O R		M O E		%Water absorption		%Thickness swelling	
	Mean	Stdev	Mean	Stdev	Mean	Stdev	Mean	Stdev
1	0.27	0.18	27.63	7.08	-	-	-	-
2	0.45	0.25	40.51	9.74	-	-	-	-
3	0.68	0.24	55.50	5.50	-	-	-	-
4	0.90	0.36	81.93	9.44	-	-	-	-
5	1.22	0.17	101.59	10.48	-	-	-	-
6	1.60	0.26	132.07	10.90	-	-	-	-
7	2.05	0.35	176.75	6.74	-	-	-	-
8	0.43	0.11	41.94	5.19	-	-	-	-
9	0.88	0.31	62.98	7.97	-	-	-	-
10	1.33	0.18	96.87	15.35	-	-	-	-
11	1.62	0.19	124.48	4.90	-	-	-	-
12	2.23	0.43	181.23	8.04	-	-	-	-
13	3.44	0.61	253.89	24.63	-	-	-	-
14	4.86	0.68	328.54	12.69	-	-	-	-
15	5.13	0.26	455.94	31.39	105.8	13.42	14.6	0.36
16	5.60	0.30	483.93	35.99	92.5	8.69	13.9	0.42
17	6.71	0.46	520.05	11.12	70.2	11.08	11.5	1.18
18	7.08	0.62	540.11	15.54	74.3	12.01	7.9	0.60
19	8.38	0.60	587.56	15.64	68.1	7.00	6.8	0.63
20	9.22	0.71	640.04	34.62	50.5	11.04	5.8	0.40
21	7.05	0.44	531.11	24.74	73.3	10.26	11.1	0.51
22	6.27	0.44	498.43	27.84	74.5	10.89	10.1	0.56
23	9.70	0.21	633.05	12.83	48.0	16.12	5.6	0.52
24	9.83	0.28	601.56	25.20	55.2	15.53	6.1	0.38
25	6.44	0.41	490.32	28.58	83.2	11.52	13.1	0.75
26	8.10	0.10	545.78	9.79	65.5	3.33	9.8	0.87
27	7.20	0.30	429.09	16.48	62.6	7.50	7.5	0.85
28	10.83	0.26	670.93	27.13	40.8	4.52	4.7	0.62
29	2.24	1.11	205.05	26.00	144.4	12.72	72.6	4.63
30	4.92	0.62	377.95	25.95	106.0	10.61	33.8	3.78

Table A.1 Mechanical and physical properties of particleboards and general commercial gypsum board (to)

Samples	M O R		M O E		%Water absorption		%Thickness swelling	
	Mean	Stdev	Mean	Stdev	Mean	Stdev	Mean	Stdev
31	4.94	0.43	315.14	25.78	112.2	9.22	37.6	2.59
32	7.20	0.70	498.08	26.00	70.7	11.57	19.6	1.43
33	0.61	0.20	5.48	2.47	382.2	17.51	1.4	0.44
34	1.06	0.29	88.39	27.02	161.6	11.67	5.6	2.18
35	0.63	0.22	6.84	3.18	318.9	16.35	1.1	0.16
36	1.84	0.57	137.25	22.21	141.9	11.91	4.0	1.94
37	0.74	0.28	51.99	12.99	209.5	9.49	8.8	0.58
38	1.32	0.20	107.13	18.00	187.1	10.26	7.5	0.84
39	4.95	0.75	445.93	22.66	115.8	17.70	16.9	1.11
40	6.23	0.35	513.42	23.01	90.3	10.27	12.6	0.32
41	2.07	0.29	137.10	9.90	150.8	9.45	5.0	0.86
42	2.92	0.56	196.94	13.43	132.7	9.55	3.8	0.35
Gypsum board	3.09	0.20	269.37	29.06	51.5	0.73	2.3	0.06

Table A.2 Sound Pressure Level at various frequencies of particleboards and general commercial gypsum board

Samples	Sound Pressure Level (dB) at frequency of				
	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
15	60.9	64.8	62.9	58.7	56.6
16	60.8	65.1	62.8	58.5	56.6
17	60.7	65.2	62.9	58.4	56.4
18	55.8	65.0	62.6	58.7	56.3
19	53.3	64.7	62.5	58.7	56.1
20	60.5	64.8	62.5	58.6	56.0
21	60.7	64.9	62.7	58.5	56.4
22	60.8	64.8	62.8	58.5	56.8
23	60.4	64.8	62.4	58.6	56.4
24	60.3	64.7	62.3	58.4	56.3
25	60.8	65.2	63.0	59.1	56.8
26	60.7	64.9	62.3	57.8	55.9
27	60.5	64.9	62.8	58.8	56.8
28	60.3	64.8	61.9	57.6	55.4
29	59.9	64.8	61.6	56.5	55.3
30	60.9	64.9	62.4	58.1	56.0
31	59.9	64.7	61.4	56.3	54.9
32	60.3	64.8	62.1	57.5	55.4
33	61.6	65.5	69.5	66.7	65.2
34	60.0	64.3	58.6	56.6	54.9
35	61.7	65.6	69.4	66.5	65.1
36	59.7	64.1	58.0	56.3	54.4
37	60.3	64.1	62.8	61.7	60.4
38	59.9	63.6	62.7	61.5	60.3
39	60.9	64.9	62.9	58.9	56.7
40	60.7	64.5	62.7	58.9	56.6
41	60.6	64.8	59.1	56.7	54.9
42	60.6	64.4	58.9	56.7	54.4
Gypsum board	60.4	65.0	62.9	59.4	57.4

Sound Pressure Level (dB) of without any boards at various frequency were as follows : 63.0 dB for 250 Hz, 66.8 dB for 500 Hz, 71.0 dB for 1000 Hz, 70.0 dB for 2000 Hz and 69.0 dB for 4000 Hz.

Table A.3 Samples designation of thermal conductivity of particleboards

Samples designation at Department of science service Ministry of science and technology	Samples designation in this thesis studied
UF 2	Sample 33
UF 3	Sample 34
UF 4	Sample 21
PF 2	Sample 35
PF 3	Sample 36
PF 4	Sample 23

The following data are thermal conductivity results of above samples which analysed by *Department of science service, Ministry of science and technology.*

DEPARTMENT OF SCIENCE SERVICE
RAMA VI ROAD, RATCHATHEWI DISTRICT
BANGKOK 10400, THAILAND

No. 0307/ 15195

Department of Chemistry,
Faculty of Science, King Mongkut
Institute of Technology Ladkrabang.

21 October 2004

Dear Sirs,

With reference to your request of 1 September 2004 Ref. No.5916 we are pleased to send you the following report on the sample/s of " UF 2 " received on 1 September 2004.

Yours truly,

(Ms. Tida Kerdkumrai)
Director, Physics and Engineering Program

Physics and Engineering Program
Tel. 0 2201 7130

REPORT

Sender' s Sample Designation	Marking	Laboratory No.	Thermal conductivity (W/m.K)
UF 2	-	XM.306	0.035

Sample Description : Square sheet.
Tested Date : 5 October 2004
Test Method : ASTM C-177

Approved by
(Mr.Puckanai Thongthiumporn)
Scientist 8

Reported by
(Mr.Puckanai Thongthiumporn)
Scientist 8

DEPARTMENT OF SCIENCE SERVICE
RAMA VI ROAD, RATCHATHEWI DISTRICT
BANGKOK 10400, THAILAND

No. 0307/ 15196

Department of Chemistry,
Faculty of Science, King Mongkut
Institute of Technology Ladkrabang.

21 October 2004

Dear Sirs,

With reference to your request of 1 September 2004 Ref. No.5916 we are pleased to send you the following report on the sample/s of " UF 3 " received on 1 September 2004.

Yours truly,

(Ms. Tida Kerdkumrai)
Director, Physics and Engineering Program

Physics and Engineering Program
Tel. 0 2201 7130

REPORT

Sender' s Sample Designation	Marking	Laboratory No.	Thermal conductivity (W/m.K)
UF 3	-	XM.307	0.049

Sample Description : Square sheet.
Tested Date : 6 October 2004
Test Method : ASTM C-177

Approved by
(Mr.Puckanai Thongthiumporn)
Scientist 8

Reported by
(Mr.Puckanai Thongthiumporn)
Scientist 8

DEPARTMENT OF SCIENCE SERVICE
RAMA VI ROAD, RATCHATHEWI DISTRICT
BANGKOK 10400, THAILAND

No. 0307/ 15197

Department of Chemistry,
Faculty of Science, King Mongkut
Institute of Technology Ladkrabang.

21 October 2004

Dear Sirs,

With reference to your request of 1 September 2004 Ref. No.5916 we are pleased to send you the following report on the sample/s of " UF 4 " received on 1 September 2004.

Yours truly,

Tida Kerdkumrai

(Ms. Tida Kerdkumrai)

Director, Physics and Engineering Program

Physics and Engineering Program
Tel. 0 2201 7130

REPORT

Sender' s Sample Designation	Marking	Laboratory No.	Thermal conductivity (W/m.K)
UF 4	-	XM.308	0.057

Sample Description : Square sheet.
Tested Date : 11 October 2004
Test Method : ASTM C-177

Approved by

(Mr.Puckanai Thongthiumporn)
Scientist 8

Reported by

(Mr.Puckanai Thongthiumporn)
Scientist 8

DEPARTMENT OF SCIENCE SERVICE
RAMA VI ROAD, RATCHATHEWI DISTRICT
BANGKOK 10400, THAILAND

No. 0307/ 15199

Department of Chemistry,
Faculty of Science, King Mongkut
Institute of Technology Ladkrabang.

21 October 2004

Dear Sirs,

With reference to your request of 1 September 2004 Ref. No.5916 we are pleased to send you the following report on the sample/s of " PF 2 " received on 1 September 2004.

Yours truly,

Tida Kerdkumrai

(Ms. Tida Kerdkumrai)
Director, Physics and Engineering Program

Physics and Engineering Program
Tel. 0 2201 7130

REPORT

Sender' s Sample Designation	Marking	Laboratory No.	Thermal conductivity (W/m.K)
PF 2	-	XM.310	0.042

Sample Description : Square sheet.
Tested Date : 13 October 2004
Test Method : ASTM C-177

Approved by

(Mr.Puckanai Thongthiumporn)
Scientist 8

Reported by

(Mr.Puckanai Thongthiumporn)
Scientist 8

DEPARTMENT OF SCIENCE SERVICE
RAMA VI ROAD, RATCHATHEWI DISTRICT
BANGKOK 10400, THAILAND

No. 0307/ 15200

Department of Chemistry,
Faculty of Science, King Mongkut
Institute of Technology Ladkrabang.

21 October 2004

Dear Sirs,

With reference to your request of 1 September 2004 Ref. No.5916 we are pleased to send you the following report on the sample/s of " PF 3 " received on 1 September 2004.

Yours truly,

Tida Kerdkumrai

(Ms. Tida Kerdkumrai)
Director, Physics and Engineering Program

Physics and Engineering Program
Tel. 0 2201 7130

REPORT

Sender' s Sample Designation	Marking	Laboratory No.	Thermal conductivity (W/m.K)
PF 3	-	XM.311	0.061

Sample Description : Square sheet.
Tested Date : 14 October 2004
Test Method : ASTM C-177

Approved by
(Mr.Puckanai Thongthiumporn)
Scientist 8

Reported by
(Mr.Puckanai Thongthiumporn)
Scientist 8

DEPARTMENT OF SCIENCE SERVICE
RAMA VI ROAD, RATCHATHEWI DISTRICT
BANGKOK 10400, THAILAND

No. 0307/ 15201

Department of Chemistry,
Faculty of Science, King Mongkut
Institute of Technology Ladkrabang.

21 October 2004

Dear Sirs,

With reference to your request of 1 September 2004 Ref. No.5916 we are pleased to send you the following report on the sample/s of " PF 4 " received on 1 September 2004.

Yours truly,

Tida Kerdkumrai

(Ms. Tida Kerdkumrai)
Director, Physics and Engineering Program

Physics and Engineering Program
Tel. 0 2201 7130

REPORT

Sender' s Sample Designation	Marking	Laboratory No.	Thermal conductivity (W/m.K)
PF 4	-	XM.312	0.072

Sample Description : Square sheet.
Tested Date : 15 October 2004
Test Method : ASTM C-177

Approved by

(Mr.Puckanai Thongthiumporn)
Scientist 8

Reported by

(Mr.Puckanai Thongthiumporn)
Scientist 8

The above report is valid for the received sample/s only. The report does not guarantee any such material of the same brand or marking which may be sold in the market
THIS REPORT IS NOT TO BE USED FOR ADVERTISING PURPOSES.

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	2002 – 2005 : Master of Science Degree, Major in Polymer Technology,
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	(Thailand) Ltd .
	1996 – 2000 : *Chemist* of Siam Chemical Industry Co., Ltd.