CHAPTER 2

THEORY AND LITERATURE REVIEW

Wood can be modified by either physical or chemical means, or their combinations. This modification is involved impregnation wood with chemicals under pressure. Impregnation involves depositing of chemicals in the microscopically visible void structure or with in the cell walls, or reacting the chemicals with the cell walls components without breaking down the wood structure.[2]

The impregnation of wood with vinyl monomers such as styrene, methyl methacrylate, acrylonitrile and vinyl acetate, and the subsequent polymerization of those monomers *in situ* to improve the dimensional stability and other properties of the wood are well known. Polymerization is induced either by the action of high energy radiation on the monomer or by the thermal decomposition of a chemical free radical precursor. Finally, the wood polymer is fabricated into the final product.

2.1 Properties of Wood

2.1.1 Structure of Wood

In dealing with the structure of wood, it is necessary to differentiate between the structure of softwood and that of hardwood in order to justify certain differences which become evident later on when discussing factors affecting strength.

Softwood is composed of relatively long needle-like cells known as "trachieds", these being orientated in the direction of the main axis of wood. These trachieds are thin-walled cells in the early wood and thicker-walled cells in the late wood. The trachieds are seperated at frequent intervals along the main axis of the wood and also circumferentially by needle-like arrangements of smaller cells known as "ray" which radiate from the pith or heart centre of the tree to outer part, their function in the growing tree being that of lateral conduction.

Hardwood which is also of cellular construction, is composed of relatively small cells known as "fibres" and very much larger cells known as "vessels" orientated in the direction of the main axis of the wood in a similar manner to that of tracheids in a softwood. In a hardwood the main function of the vessels is to provide pathways for conduction and that of the fibres to provide structural strength. The vessels or pores in hardwood are arranged either in regular rings, in which case the timber is classified as a "ring-porous" species, or alternatively, the vessels are uniformly distributed, the timber then being classified as a "diffuse-porous" species.

In ring-porous species of hardwood the vessels are generally surrounded by parenchyma cells, the vessels and the parenchyma cells together forming a band of low density material comparable with the early wood of softwood.

The primary function of the parenchyma cells in hardwood is that of food storage in the growing tree.

In the diffuse-porous species of hardwood the parenchyma cells are generally arranged in rings around individual vessels and consequently the structure of the wood is of a more uniform density than in the ring-porous species.

In both ring-porous and diffuse-porous species of hardwood the fibres and vessels are seperated by rays in a similar way to that of the seperation of the tracheids in softwood. The rays in hardwood, however, usually have a greater number of cells than the rays in softwood and moreover are generally much broader being several cells in thickness or "multi-seriate", where as the rays in softwood are usually only a single cell in thickness or "uni-seriate".

The tracheids in softwood and the fibres and vessels in hardwood follow a fairly regular and a similar pattern in that they are coaxially arranged side by side overlapping each other longitudinally in a random bonded pattern, the tapered ends of the cells forming overlapping end-to-end joints. The regularity of this arrangement, however, is interrupted by the cells forming the rays which, as mentioned earlier, are interspersed and separate the fibres at frequent intervals.

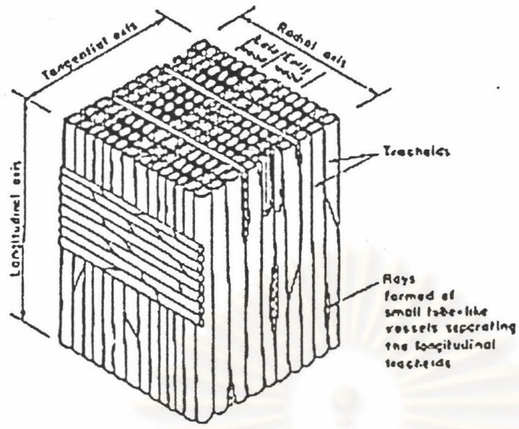

Fig.2.1 Structure of softwood.

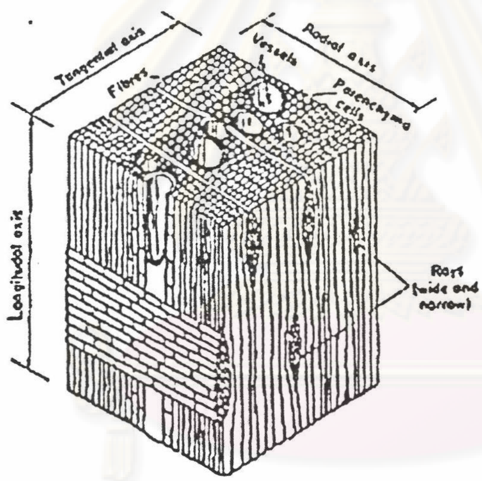

Fig.2.2 Structure of hardwood. [3]

From the foregoing general description it will be appreciated that softwood and hardwood are very similar in their main structural features and both can be regarded as being composed of bundles of thick and thin-walled cells or tubes orientated in the direction of the main axis of the wood with small bundles of smaller tubes orientated at right-angles to them and separate them at intervals longitudinally and radially.

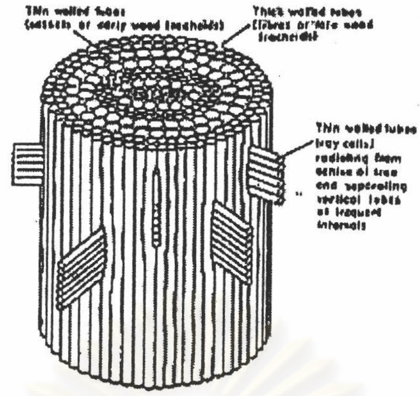

Fig.2.3 Schematic diagram of structural elements of wood.[3]

A brief description of the structure of the cells and the way in which these are linked together to form the complete wood structure is also necessary in order to understand the reasons for certain phenomena that affect the strength properties of wood, the structure of which, so far, has been discussed only in very general terms.[3]

Grain.

The wood from trees of rapid growth will have wide annual growth rings and is called coarse-grained. On the other hand wood from slow-growing trees has narrow growth rings and is often called closed-grained. Straight grain and cross grain are used to describe wood in which the fibers are parallel to, or at an angle to, the side of piece. [4]

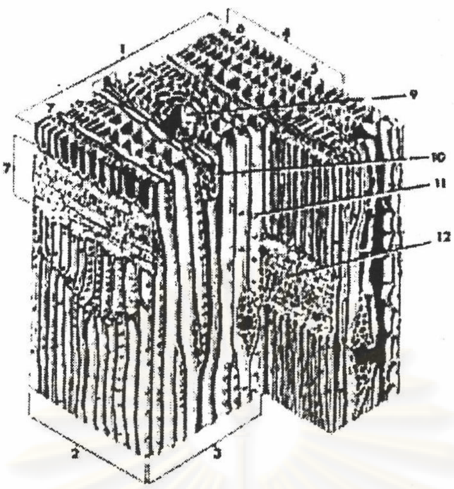

Fig.2.4 Cellular structure of a softwood: (1) cross section, (2) radial section, (3) tangential section, (4) growth ring, (5) earlywood, (6) latewood, (7) wood ray, (8) fusiform ray, (9) vertical resin duct, (10) horizontal resin duct, (11) bordered pit, (12) simple pit.[5]

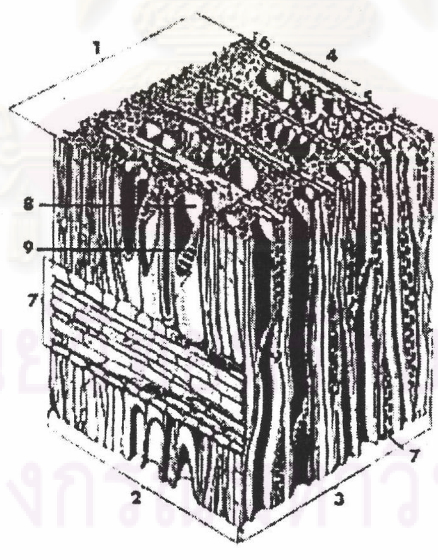

Fig.2.5 Cellular structure of a hardwood: (1) cross section, (2) radial section, (3) tangential section, (4) growth ring, (5) earlywood, (6) latewood, (7) wood ray, (8) vessel, (9) perforation.[5]

2.1.2 Sapwood and Heartwood

Sapwood contains living cells and has an active part in the life processes of the tree. It is located next to the cambium and functions in sap conduction and storage of food.

The sapwood layer may vary in thickness and in the number of growth rings contained in it. Sapwood commonly ranges from 1.5 to 2 inches in radial thickness. In certain species, such as chestnut and black locust, the sapwood contains very few growth rings and sometimes does not exceed one-half inch in thickness. The maples, hickories, ashes, some of the southern yellow pines, and ponderosa pine may have sapwood 3 to 6 inches or more in thickness, especially in second-growth trees. As a rule, the more vigorously growing trees of merchantable size consist mostly of sapwood.

Heartwood consists of inactive cells formed by changes in the living cells of the inner sapwood rings, presumably after their use for sap conduction and other life processes of the tree have largely ceased.

The cavities of heartwood also may certain deposits of various materials that frequently give much darker color to the heartwood.

Heartwood having pores tightly plugged by tyloses, as in white oak, supplies lumber suitable for tight cooperage.The infiltrations or materials deposited in the cells of heartwood usually make lumber cut from it more durable when used in exposed situations than that from sapwood. Unless treated, all sapwood is nondurable when exposed to weather.

There is no consistent difference between sapwood and heartwood in weight when dry and in strength. These properties are influenced more by growth conditions of trees at the time the wood is formed than they are by the change from sapwood to heartwood.[6]

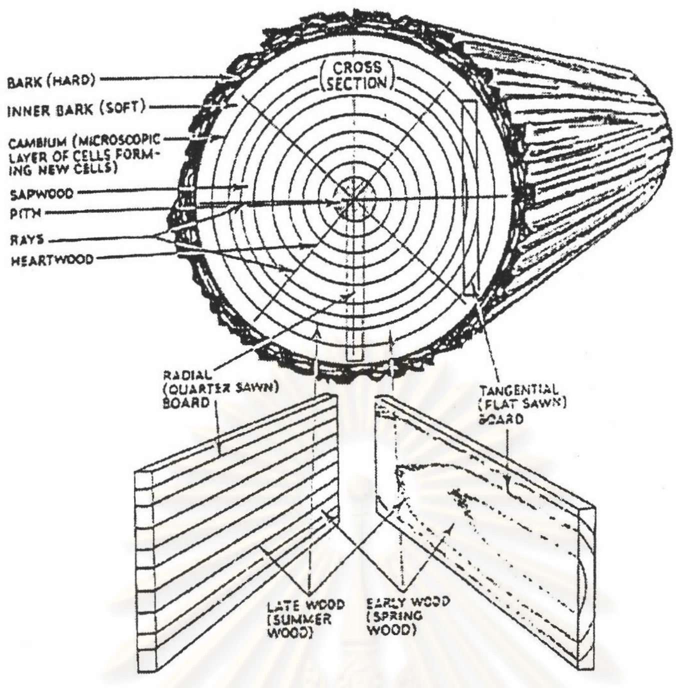

Fig.2.6 Characteristic of log and timber[7]

2.1.3 Physical properties of Wood

Moisture content. Wood contains a considerable amount of free water within its cell walls. After a tree is cut it begins to lose moisture, and the moisture content continues to drop throughout the entire manufacturing process.

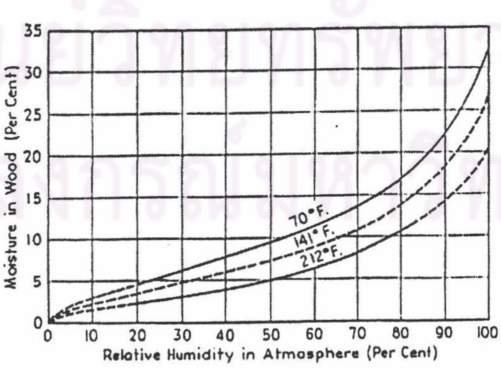

Fig.2.7 Humidity-moisture-content relationship at three temperatures.[4]

This moisture content is defined as the weight of water contained in wood expressed as a percentage of the weight of oven-dry wood. When put into use, wood will continue to dry until it is in equilibrium with the surrounding atmosphere. By equilibrium moisture content is meant the ultimate moisture content depending upon the temperature and the relative humidity in the atmosphere, that wood will attain. Fig.2.7 shows the average relationship between the moisture content of wood and the relative humidity of the surrounding atmosphere at three temperatures.

Wood is said to have reached the fiber saturation point when all the free water in the cells is evaporated and the cell walls are still saturated. This point is generally reached when the moisture content is between 24 and 30 percent. As wood dries beyond the fiber saturation point it increases in strength. However, such properties as toughness or shock resistance decrease because wood in a dry condition will not bend as much as wood in a green condition. In commercial structural grades the increase in strength due to drying is to a large extent offset by the influence of defects that develop during seasoning.

Shrinkage. Shrinkage take place after the fiber saturation point has been reached. Accompanied by a reduction in moisture content is a reduction in the size of a piece, for as wood dried it also shrink. Wood shrink most tangentially or the direction of the annual growth rings and about one-half to two-thirds as much radially or across the annual rings. The longitudinal shrinkage in most woods is negligible.

Density. Density is a definite criterion of the strength of softwoods. It is determined by the rate of tree growth and the amount of summerwood present. This means that the strength of a piece of wood is being measured but the amount and distribution of wood substance, which is the material making up the cell walls. The specific gravity of this wood substance is the same for all woods, 1.54, and all woods would be of the same specific gravity throughout were it not for the difference in the arrangement and size of cells and the thickness of the cell walls. In grading softwood lumber for structural purposes, the number of rings per inch radially and the proportion of summerwood in the cross section of the piece are considered as part of specification. Material having a specified minimum number of rings per inch is termed "close-grained", and material that has in addition one-third or more of summerwood is termed "dense".[4]

2.2 Coconut Palm

2.2.1 Coconut Varieties

Coconuts *(Cocos nucifera L.)* are the most important of cultivated palms and the most widely distributed of all palms.

They are now grow in all tropical regions around the world, where the temperature, humidity, soil, and elevation are suitable. They are found near the sea.

The coconut is a diverse species which is generally divide into two groups. These groups are tall varieties and the dwarf varieties. The tall coconut is the common or typical coconut of commerce. The general characteristics of the tall coconuts are that they are long lived (up to 60 or 80 years or more), and they begin to bear fruits in 8 or 10 years from planting. They usually are the only type selected for commercial planting because of their general superiority in copra production. The dwarf varieties are smaller in stature and commence bearing fruits earlier than the tall varieties. They will often flower in the third or fourth year planting. Thus the first nuts are borne not far above the ground. They are in full production in the ninth or tenth year. The economic life of these varieties however, is only 30 to 40 years.[8]

2.2.2 Coconut Stem Anatomy

Coconuts are trees with 40-100 ft tall, and 8-24 in. in diameter. However, some trees are dwarf, some have branches, and others have spiral trunks. They are monocotyledonous, with no tap root, and have a swollen base. Since they are propagated only by seed, every tree is different with millions of variations.

Actually, coconut palm do not have the solid woody trunks that the dicots and conifers have. Their trunks are more like the stems of sweet corn. Bundle of woody water-carrying tubes are scattered through these stems. In between there is soft pith. The highest density of material is in the outer, which more than 600 kg/m^3 while the medium density is 400-600 kg/m^3 and the low density is less than 400 kg/m^3.

Coconut palm do not have vascular cambium that cause the trunk not to expand as its age. They have vascular bundles that affect the strength properties of trunk and parenchyma cells. At the first stage, they grow in radial line and only longitudinal line after that.

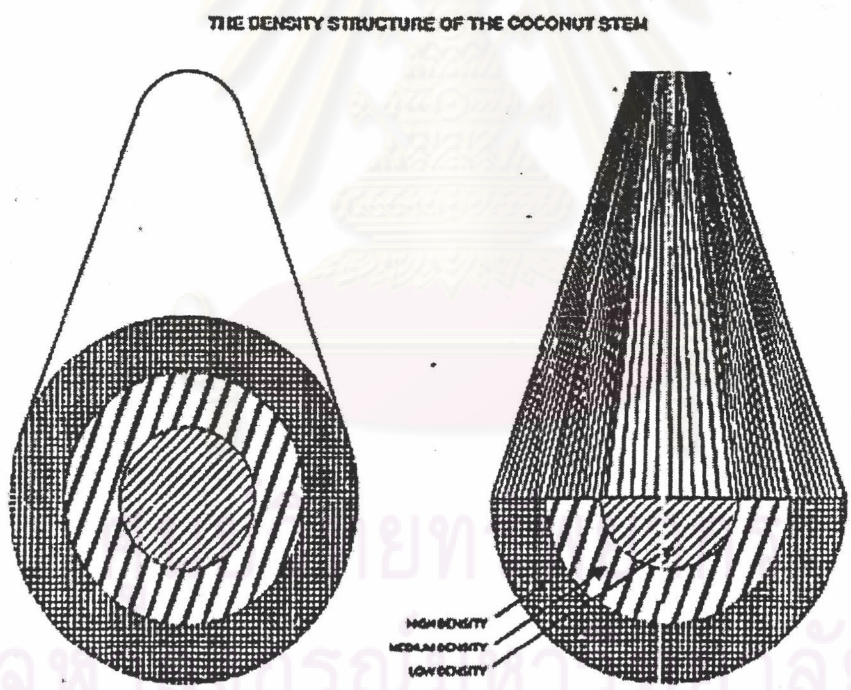

Fig.2.8 The density structure of the coconut stem [9]

2.2.3 Products of the Coconut Palm

Commercially the greatest value of the coconut lies in the oil, which is extracted from the dried kernel of the fruit. Coconut oil is popular as a cooking oil and also has a number of industrial use in products ranging from laundry detergents to non-dairy creams.

Once the palms are 50 to 60 years old, copra yield declines rapidly. So in the sixties, replanting programs were developed.

The old trees had to be removed to make room for the new ones. Left to rot, they would have encouraged the rhinoceros beetle to breed. The rhinoceros beetle attacks the young seedlings. So various coconut-growing countries considered methods to either dispose economically of the stem or to make use of it. Research activities were backed and funded partly by the government of New Zealand and the Philippines and the Food and Agriculture Unit of the United Nations. A research station in the Philippines succeeded in demonstrating the feasibility of the coconut palm as a timber source. With the depletion of forests in many parts of tropical region, leading to shortage of wood for many industrial and engineering uses, attention has been given to coconut wood as a alternative source of timber.

2.2.4 The Utilization of Coconut Timber

The wood is now becoming more widely known as having great potential due to its readily acceptance of adhesives and the uniform grain and colour within each density band. The denser the wood the darker the colour, and the least dense innermost section is much paler than the rest. The high density palm wood will do for roof trusses and window frames. Medium density wood will do suffice for staircases. And crates, pallets and boxes can still be made out of low density wood.

In Thailand, there are about 3 millions rais plantation of coconut trees, and they will be cut when they are 50-80 years. The cutting has been done for about 10 years. Because of this, each year 650,000 millions cubic metres of coconut trees are available. The coconut wood has been investigated for utilization such as, soaking them in the preservative solution, processing them by electric chainsaw, applying them in structural glue-laminated timber.

2.2.5 Physical and Mechanical Properties

Coconut stems are almost as tough as wire and the outer of stem has high density which different from common trees. The fiber is hard, sharp and the longitudinal fiber is orientated in the same direction of stem. Grain Pattern is parallel which called straight grain. Coconut wood has increased strength as its age and lower shrinkage than general trees.[1]

Table 2.1 Relationship between mechanical properties and specific gravity of coconut wood .[10]

Mechanical Properties	Unit	Coconut wood	General wood	
		Test condition	Moisture condition	
		(14-20%)	Green	Air-dry(12%)
Modulus of elasticity	kg/cm^2	180000G-35000	163000G	194000G
Compression ⊥ grain	kg/cm^2	$550G^{2.5}$	-	-
Compression // grain	kg/cm^2	750G-150	363G	605G
Shear // grain	kg/cm^2	$130G^{1.5}$	$190G^{1.33}$	$278G^{1.33}$
Impact bending	kg-m	$9G^{1.33}$	-	-
Hardness	kg	$2000G^{2.25}$	-	-

Note: G is the specific gravity of oven-dry wood

2.3 Methods for improving dimensional stability of wood

All methods for attaining improved dimensional stability of wood fall into one or more of five different types. [11]

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

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

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

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

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

2.4 Solid Modified Woods

These modifications of wood, involving only chemical treatments, thermal treatments, and densification treatments, that retain the original integrity of the wood throughout the processing. They differ from reconstituted woods, that are broken down either mechanically or chemically and then reformed into solid products, with or without the use of adhesives.

2.4.1 Fundamentals of impregnation

The most important, and frequently the only step involved in making of various modified wood products covered here involve the impregnation and distribution of various chemicals throughout the structure of wood.

Impregnation of solid wood has in general been accomplished by evacuating the wood specimens in a treating cylinder, then running in the pure monomer or monomer plus swelling agent, followed in the case of large specimens by the application of pressure. Preevacuation is desirable not only from the stand point of aiding penetration but also from the stand point of eliminating oxygen from the system as it acts as an inhibitor for subsequent polymerization by radiation. Modification of this procedure to attain virtually full loading, and reasonably more uniform distribution at partial loading. The conditions will vary with the size, shape, and extent of end grain, the species, whether sapwood or heartwood, the specific gravity of the wood and the viscosity of the treating liquid. Even when all of these factors are taken into account, only roughly constant degrees of loading can be obtained with solid wood due to the high degree of variability of wood.

Practically all of the monomers used are volatile. Because of this, some of the investigators wrapped their impregnated specimens in aluminium foil prior to irradiation.

Irradiation by gamma rays has been carried out with cobalt-60 sources of different intensity. Dose rates and times of irradiation varied with the size and shape of the sample and its position relative to the source. Care should be exercised to avoid over irradiation, as the higher total doses of irradiation have a deleterious effect upon the mechanical properties of the product.

Free radicals, like those needed to initiate the polymerization of vinyl resin, are produced on heating benzoyl peroxide thus breaking the o-o bond giving two free phenyl radicals and carbon dioxide. These free phenyl radicals have been shown to promote vinyl resin polymerization in a manner similar to gamma ray initiated polymerization.

2.4.2 Vinyl Resin treatment

Considerable interest has developed in recent years in polymerizing various vinyl resins in cellulosic material. The interest arose largely because these resins can be formed from their monomers by gamma ray irradiation which generates free radicals that act as excitation reaction sites in the system.

Although most of the fundamental research on forming vinyl polymers in cellulosic materials has been confined to cotton fibers, textiles, cellophane and paper, considerable applied research has been carried out on wood in an attempt to produced an improved modified wood product. The chief monomer used was styrene which swells wood only slightly on prolonged soaking. Because of this, when styrene was the sole impregnant, it imparted a negligible dimensional stability to wood after polymerization in the structure. Monomeric methyl methacrylate swelled the wood somewhat more than styrene but still imparted only a small dimensional stability to the wood after polymerization.[2]

2.5 The Chemical used for modified wood

2.5.1 Styrene (ST)

Styrene is a derivative of benzene. It is clear, colourless, mobile liquid that polymerizes readily. Figure 2.9 shows the structure of styrene.

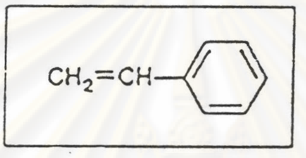

Fig.2.9 The structure of styrene

Polymerization of styrene monomers gives polystyrene. Polystyrene is a linear polymer which find widespread use in the developed world account of its desirable properties, combined with its relative cheapness. Among its features are excellent colour range, transparency, rigidity and low water absorption. It is quite resistant to alkalis, halide acids and oxidizing and reducing agents, easy to process, high refractive index, good electrical insulator, low dielectric, low resistant to impact, low heat distortion properties, brittleness and has a glass transition temperature of 80°C[12,13]

2.5.2 Methyl Methacrylate (MMA)

Methyl methacrylate is colourless liquid, almost insoluble in water and miscible with most organic solvents. Free-radical polymerization is initiated by peroxide or azo catalysts and produce poly(methyl methacrylate) resins having the following formular:

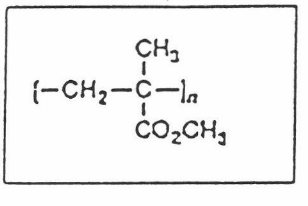

Fig.2.10 The structure of poly(methyl methacrylate)

Poly(methyl methacrylate) is a linear atactic thermoplastic. It is a clear, colorless transparent plastic with a higher softening point, better impact strength, better weatherability than polystyrene, resistance to many aqueous inorganic reagents, including dilute alkalis and acids. The mechanical and thermal properties of the polymer are good. Tensile strength ranges as high as 10,000 psi. Impact strength is about equal to that of the impact-resistant styrene copolymers. Heat-distortion temperatures are above 90°C, poor abrasion resistance compared to glass and has a high glass transition temperature of 110°C. [12,13] Mechanical Properties of Common Homopolymers are shown in table 2.2.

Table 2.2 Mechanical Properties of Common Homopolymers[a] [14]

Property / Polymer	Tensile Properties at Break			Compressive	Flexural	Impact
	Strength[b] (MPa)	Modulus[b] (MPa)	Elongation (%)	Strength[b] (MPa)	Strength[b] (MPa)	Strength[c] (N/cm)
Polyethylene, low density	8.3-31	172-283	100-650	–	–	No break
Polyethylene, high density	22-31	1070-1090	10-1200	20-25	–	0.23-2.3
Polypropylene	31-41	1170-1720	100-600	38-55	41-55	0.23-0.57
Poly(vinyl chloride)	41-52	2410-4140	40-80	55-90	69-110	0.23-1.3
Polystyrene	**36-52**	**2280-3280**	**1.2-2.5**	**83-90**	**69-101**	**0.20-0.26**
Poly(methyl methacrylate)	**48-76**	**2240-3240**	**2-10**	**72-124**	**72-131**	**0.17-0.34**
Polytetrafluoroethylene	14-34	400-552	200-400	12	–	1.7
Nylon 66	76-83	–	60-300	103	42-117	0.46-1.2
Poly(ethylene terephthalate)	48-72	2760-4140	50-300	76-103	96-124	0.14-0.37
Polycarbonate	66	2380	110	86	93	9.1

[a] Values taken from Agranoff, converted to SI units, and rounded off.

[b] To convert megapascals to pounds per square inch, multiply by 145.

[c] Izod notched impact test. To convert newtons per centimeter to foot pounds per inch, multiply by 1.75.

2.5.3 Methyl ethyl ketone peroxide (MEKP)

MEKP is used as an initiator in the experiment. It is changed in free radical form at elevated temperature and then induce monomers to polymer. It is clear, colorless, cheap, low self accelerating decomposition temperature, insoluble in water but soluble in phthalates, low conductivity and strong oxidant. The structure of MEKP is shown in fig.2.11.

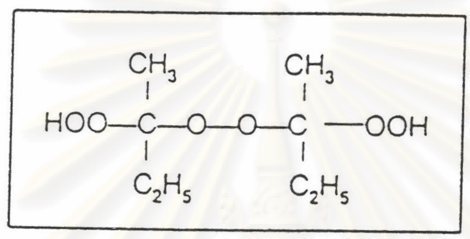

Fig.2.11 The structure of MEKP

2.5.4 Divinylbenzene

By the addition of small amounts of a divinyl compound such as divinylbenzene to styrene, controlled branching or crosslinking can be introduced into the resulting copolymer. As little as 0.0025% divinylbenzene gives soluble branched polymers. About 0.1% divinylbenzene results in an insoluble, non-thermoplastic polymer which, however, swells greatly in solvents. If 5-10% divinylbenzene is used, the product is a typical hard, brittle cross-linked material.[13] Its structure was shown in Fig.2.12.

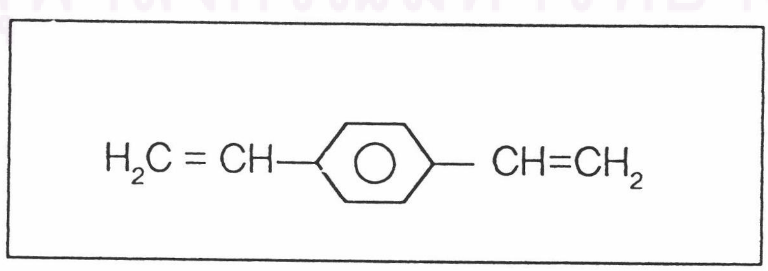

Fig.2.12 The structure of divinylbenzene

2.6 Termites

There are three types of termites – dampwood termites, drywood termites and subterranean termites.

Dampwood termites attack sick or dead trees, decaying stumps or mouldy timber in the ground. They are seldom found in dry timbers in buildings. They form small independent nests.

Drywood termites occur mostly in tropical areas, where the atmospheric humidity is constantly above 75 percent.

Subterranean termites are the serious pest species involved in major structural timber damage to building. They cause about 95% of structural timber pest damage to homes. They build a central nest from which they make used of underground tunnels to randomly forage for a timber (cellulose) source within 50 to 100 metres from the nest. If they make contact with a hard object such as brick pier or concrete slab flooring they build mud- shelter tubes protect them from ants and other enemies and prevents dehydration as high humidity is essential for their survival.

Termites are very soft bodied insects. When ever you encounter termites, they will not do you any physical harm whatsoever, excepting at worst, the nervous stress caused by the termites eating your house down.

They build a central nest often containing over one million termites, and have an extremely well ordered social system with engineer capabilities and a survival instinct developed over two hundred million years of evolution. They were on this earth before flowering plants. They grow fungi in their nest as a protein source and the worker caste obtain cellulose (such as, in timber) as the colony's energy source. They obtain moisture from the soil and moist decaying timber. They need to maintain a high level of humidity and temperature (25 to 35°c) in their central nest. They will eat through the centre of timbers leaving nothing but the outside coat of paint or a thin veneer of timber. The main species of subterranean termites found in the world that cause damage to buildings or timber structures are classified in seven types.

1. *Coptotermes acinaciformis* – the most widely distributed and destructive timber; a single colony many consist of well over one million termites; a very secretive termite; they build their nest out of sight, within the base of eucalyptus or other susceptible trees, or completely under the ground often within enclosed patios or under concrete on ground flooring which is ideal for moisture retention, temperature and humidity control within the nest; this species may produce a sub-nest away from the main colony nest and be contained in a well cavity of a building where a reliable moisture source is available.

2. *Schedorhinotermes intermedius* – a serious timber pest that can cause extensive structural timber damage to buildings; they commonly nest in tree stumps and under houses or in enclosed patios where timber has been buried or stored on the ground.

3. *Nasutitermes exitiosus* – attacks buildings in which severe damage may occur; their nest protudes 30 to 75 cm. above the ground.

4. *Nasutitermes walkeri* – they build their nest in trees on the main trunk or in the fork of a large branch; will attack damp timber; usually a problem where the sub-floor of a building is damp and ventilation is poor that allows wood decay/fungi growth.

5. *Coptotermes frenchi* – primarily a tree pest, but has caused significant damage to buildings.

6. *Heterotermes ferox* – attacks mainly fences ana similar structures subject to wood decay from weathering.

7. *Coptotermes lacteus* – attacks dead wood in the ground; builds its nest an a mound up to 2 m. high with hard clay walls; not considered a serious pest of buildings.

2.7 Water and polymer location

The mechanism of water absorption by drywood proceeds in two steps. Water entering dry wood in vapor form is absorbed in the cell wall, and hydrogen bonds to the cellulose. As a result, the cell wall swells, and the overall dimensions of the wood increase. After 25-28% of the water is absorbed (based on the oven-dry weight of the wood) and the cell wall has swollen to its maximum, additional water will be condensed in the capillaries or other void spaces in the wood until it is filled. The fiber-saturation point is where the cell walls have absorbed the maximum amount of water and are swollen to the maximum extent, but no water has condensed in the capillaries. Normal wood-polymer material contains polymer only in the void spaces that are available, and little if any in the cell walls. This loading of the capillary vessels reduced the rate of water diffusing into the cell walls. But, given enough time (10-20 fold greater than in untreated wood) at high humidity, eventually water will reach the cell walls and caused the same volume swelling as untreated wood.[15]

2.8 Statistical analysis ; oneway-ANOVA

Hypothesis

$H_o : \mu_1 = \mu_2 = ... = \mu_n$ (mean same)

$H_1 : \mu_i \neq \mu_j \; ; i \neq j \; ; i, j = 1, 2, ...n$ (mean difference)

* The mean difference is significant at 0.05 level

The objective of oneway-ANOVA is testing of mean between the difference of people who get three or more different factors and fix groups that get the same factors are same groups, where as groups that get different factors are different groups.

2.9 Literature review

Wood polymer composite (WPC), had been interested by scientists since 1930. It exhibited improvement in strength, dimensional stability, and resistant to biodeterioration. The extent of improvement in property was directly related to the polymer content, which, in turn, was dependent on the type of wood, the nature of the polymer, and the processing applied. In this literature survey, various monomer, co-monomer, catalysts or initiators for preparation of wood-polymer composites are summarized as follows:

Rozman, H.D., Kumar, R.N. and Abusamah, A. [16] studied the wood-polymer composites of rubberwood *Hevea brasilienis*, prepared by impregnating the wood with methyl methacrylate (MMA), and the combinations of MMA and diallyl phthalate (MMA/DAP). Polymerization was carried out by catalyst heat treatment in the present of catalyst. The result showed significant improvements of 27-83% in compressive, 34-102% in impact strengths, 33-233% in hardness and 30-43% in antiswell efficiency over that of the untreated rubberwood.

Yalinkilic, M.K. and co-workers [17] studied enhancement of biological and physical properties of wood by boric acid-vinyl monomer combination treatment. Sapwood of *Cryptomeria japonica D.* was impregnated by boric acid, styrene and methyl methacrylate and then polymerized by heat radiation. The result showed that vinyl monomer succeeded in reducing water absorption from 338% of untreated wood to 23-31% of treated wood and delay boron leaching considerably. The treated wood proved to be resistant against two decay fungi and very destructive termite even after ten severe weathering cycles. Boric acid increased the oxygen index levels of monomer-treated wood which resulted in a lower flame spread index. Moreover, boric acid suppressed the smoke generation due to monomer cooperation in wood.

Hazer, B., Ors, Y. and Alma, M.H. [18] investigated the improvement of wood properties by impregnation with macromonomeric initiators (macroinimers) and styrene, leading to crosslinked block copolymers of styrene and poly(ethylene glycol). Weight gains of 36.37-91.13% were obtained after polymerization wood was found to be 35.13-72.07% and the water-repellent effectiveness of 35.14 - 58.15 % , after a water soaking test of 144 hours. The antiswell efficiency (ASE) value increase with an increase in weight percent gain. Improvements of 19.12% in longitudinal compression and 25% in bending strength were also achieved for spruce samples with low weight percent gain. IR spectroscopy was used for chemical characterization of the wood-polymer composite.

Mathias, L.J., Soo, L., Wright, J.R. and Warren, S.C. [19] improved wood properties by impregnation with multifunctional monomer ethyl α - hydroxymethylacrylate (EHMA) and fluorinated or nonfluorinated crosslink agent. Impregnation with EHMA plus another multifunctional monomer 2-vinyl-4,4-dimethyl-2-oxazolin-5-one (vinyl azlactone) was carried out to improve the mechanical properties, water repellency, 38-54% in impact strength, 27-44% in compression modulus. FTIR and solution or solid-state NMR spectroscopy were used for chemical characterization of the polymer themselves and the wood-polymer composites.

Elvy, S.B., Dennis, G.R. and Loo-Teck, N.G. [20] studied the catalyst-accelerator method for preparation of wood-polymer composite at ambient temperature and reduce the loss of the volatile monomer during curing, which is a major disadvantage of the heat-catalyst method. The combination of peroxide initiators with an aromatic amine accelerator was optimized for the methyl methacrylate system. Polymer loading of samples were 0, 100.3 and 100.1%, hardness for all three faces of samples were 2.83-3.83, 14.45-15.85 and12.5 kN for untreated wood, WPC prepared by the catalyst-accelerator method and WPC prepared using gamma radiation, respectively. The catalyst –accelerator method has been shown to have advantages over the gamma-radiation curing method.

Hadi, Y.S., Nawawi, D.S., Herliyana, E.N. and Lawniczak, M. [21] investigated termite attack resistance of four polystyrene-impregnated woods from Poland by using N-metylolmetacrilamide as the initiating agent. The results showed that the average weight gains for *Alnus glutinosa*, *Populus maximowiczii*, *Salix alba* and *Pinus silvestris* were 106, 135, 123 and 88 percent, respectively, and these wood species had similar resistance to termite attacks. Polystyrene – impregnated wood had more resistance to dry wood termite and subterranean termite attacks than the control wood.

Alma, M.H., Maldas, D., Hafizoglu, H. [22] studied water repellency of several wood species which were prepared as wood polymer composites (WPC) with styrene (St) and a mixture of styrene and methyl methacrylate (St-MMA) monomers using capillary uptake method. The average water uptake of the monomers treated wood was approximately between 43 to 64 % after water soaking for 72 h. The average water repellent effectiveness (WRE) of WPC was 54% and 55% for St and St-MMA, respectively.

Rungsri, S. [23] improved rubberwood properties by impregnation with methyl methacrylate/acrylamide(MMA/AM) and methyl methacrylate/2-ethylhexyl acrylate (MMA/2-EHA). Impregnated samples containing MMA/AM gave low polymer loading at 22.04-30.56%, but MMA/2-EHA gave higher polymer loading at 56.08-60.00%. Water absorption was increased with increasing the ratio of AM and 2-EHA. For the mechanical properties of WPC with MMA/AM, the MOE, flexure stress, and compression were the highest at 80:20 ratio, which were 7992.7 MPa, 122.25 MPa and 70.99 N/mm,^{2} respectively. When MMA/2-EHA was used, the MOE, flexure stress, and compression were the highest at 20:80, 20:80 and 80:20 ratios which were 8699 MPa, 130.24 MPa and 77.36 N/mm,^{2} respectively.

Sukhonphanich, A. [24] investigated the improvement of rubberwood properties by impregnation with styrene/butylacrylate (ST/BT) and styrene/acrylamide (ST/AM). The rubberwood poly(ST/BT) and poly(ST/AM) obtained from the optimum conditions gave 18-34% of water absorption which was lower than that of natural para rubberwood. Mechanical properties such as modulus of elasticity, flexure stress, compression were at about 7951-10165 MPa, 115-159 MPa, 67-90 MPa, respectively, which were higher than those of natural para rubberwood.

Rungvichaniwat, C. [25] improved rubberwood properties by impregnation with epoxy resin mixture under reduced pressure. The results showed that 30 phr. reactive diluent and 27 phr. hardener content were suitable for impregnating prepolymer mixture into para rubberwood matrix. Para rubberwood-epoxy resins composites were decreased 27% in water absorption and increased 44.83% in antiswell efficiency, 103.62% in modulus of elasticity, 58.76% in flexure stress, 71% in compression when compared to natural para rubberwood.

Kasamchainanta, B. [26] investigated the improvement of durianwood properties with polyester resins by impregnation method. The results showed that 90% by wt. of polyester resins, 10% by wt. of styrene monomer and 1 phr. benzoyl peroxide were suitable for impregnating prepolymer mixture into durian matrix. Impregnated samples were improved as 53% in density, 87% in hardness, 105.7% in modulus of elasticity, 101.7% in flexure stress and 44.5% in compression when compared to durianwood.