

CHAPTER II

THEORY AND LITERATURE REVIEW

Wood is a basic and essential raw material. Worldwide, something approaching 3,000 million tonnes is harvested annually. Wood products are the third most important commodity by weight, after fossil fuel and quarry products. More than 100 million tonnes of wood are shipped around the world each year to correct for local imbalance in supply. Patently trees are a renewable resource. However, it is an oversimplification to assume that the supply is without limit and, more particularly, that sufficient material of construction quality will be available in the future.

Presently the demand for structural lumber products for building materials has increased with increasing construction of housing. On the other hand, the quantity and quality of wood resources from the forest have been decreasing. Consequently, the search for substitute materials in place of the traditional uses of wood has been the focus of renewed interest. Reconstituted wood panels have been remarkably successful in this substitution. Their uniformity, cost and ease of machining have led not only to the replacement of solid wood but has extended the use of wood-based products into new consumer applications, with consequent increase in the standard of living. The principal requirement for structural timber is load bearing, which requires high stiffness for minimum weight and low creep value. In addition the material must be durable, and able to retain fastenings; of necessity, the strength properties must be highly directional. Wood satisfies these requirements very well, except for a tendency to creep under steady but less than critical load. Its behavior derives from its unique structure-high strength fibres sparingly coated with a durable polymeric resin and arranged in a cellular pattern to produce a remarkable degree of anisotropy (Figure 2.1). The same cellular structure will close about and retain fastenings strongly. This structure is not greatly changed when wood stems are reduced to strands in the impregnation process and the product therefore inherits the properties of the parent wood.

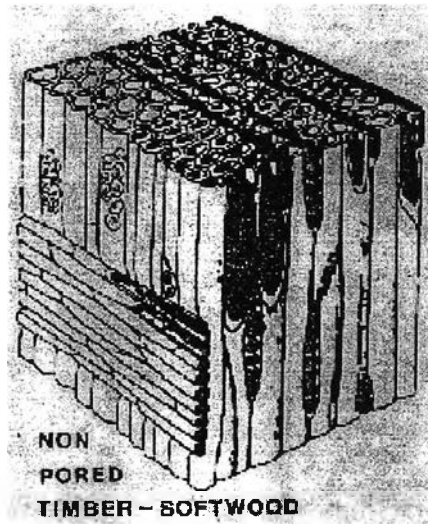


Figure 2.1 The Unique Cell Structure of Non-pored Timber-Softwood

2.1 Hardwoods and Softwoods [4]

All commercially important tree species are either hardwoods (angiosperms, which are the broad-leaved, dicotyledencus species) or softwoods (gymnosperms, which are the coniferous species with needle-shaped or scale-like leaves). In temperate zones, the majority of hardwoods are deciduous while most softwoods are evergreen. At the microscopic level, the distinction between hardwoods and softwoods is determined by the types of cell found in the secondary xylem. The component cell types are arranged into the axial system, and are therefore aligned with the vertical orientation of the standing tree, and the ray system composed of cells which radiate out as sheets or plates from the central region to the perimeter of the tree trunk. (Figure 2.2) The structure of individual cells and the arrangement of these cells into tissue zones reflects their function with the living tree by providing mechanical strength, acting as water-conducting elements and functioning as storage or secretory cells.

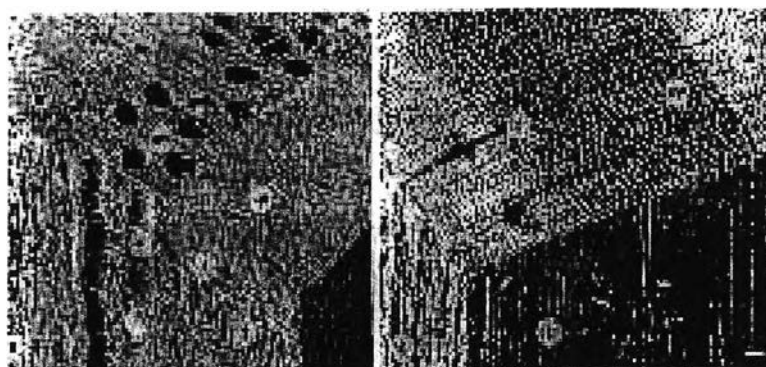


Figure 2.2 Scanning electron micrographs of (right) Ash and (left) Scots pine

Table 2.1 Cell Types in Hardwoods and Softwoods

Axial cells	Transverse cells
Hardwoods	
- Vessel element	- Ray parenchyma cell
- Tracheid	- Ray epithelial cell
- Fibre	
<i>Fibre tracheid</i>	
<i>Libriform fibre</i>	
- Axial parenchyma cell	
- Epithelial cell	
Softwoods	
- Tracheid	- Ray tracheid
- Axial parenchyma cell	- Ray parenchyma cell
- Epithelial cell	- Ray epithelial cell

In hardwoods, the main strength of the timber is provided by libriform fibres and fibre tracheids. In softwood timbers, the strength of the wood is derived largely from the latewood tracheids which form during the latter part of the growing season and produce a dense region of cells in each annual growth ring. This band of latewood tracheids is composed of thick-walled cells with small lumina and contrasts sharply with the wide diameter, thin-walled cells in the

adjacent earlywood zone of the next annual growth ring (Figure 2.3). These larger diameter tracheids in softwoods have a water-conducting and nutrient transfer function in the living tree and are considered of lesser importance in providing mechanical strength to the wood. In softwoods, the tracheids are considered to make up more than 90% of the total wood volume.

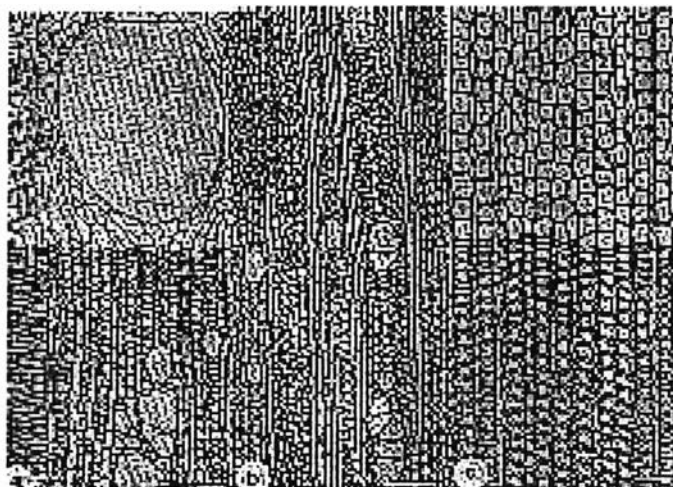


Figure 2.3 Transverse sections of annual growth rings in (a) a ring-porous hardwood, (b) a diffuse-porous hardwoods, (c) a softwood showing large-diameter, thin-walled earlywood cells and small-diameter, thick-walled latewood cells.

Non-structural reconstituted panels are composed of wood particles or flakes. Considerable effort has been directed toward developing mechanical techniques to develop physical and mechanical properties. Increased research during recent years has contributed considerably to improve the properties for wider use. Rubber wood, in particular, is considered a promising alternate raw material because of its fast growth rate, short rotation age, cheap, and high mechanical strength. The use of rubber wood has expanded to include its manufacture into various structural composite boards, such as plywood, particleboard, furniture, stationery, construction material, etc. Up to now, few investigations have been done on the utilization of rubber wood for manufacturing wood-polymer composites (WPC) by impregnation.[5]

2.2 Rubber wood

2.2.1 Technical properties and utilization of rubber wood

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

Rubber trees grow to a height of 25 meters and generally have straight trunks. Usually, at the time of felling, the girth varies between 100 to 110 centimeters, at a height of 125 centimeters above the ground and gives 0.62 cubic meters of stump wood and 0.40 cubic meters of branch wood. At the time of felling, usually it contains 180 to 185 trees per hectare.[6]

2.2.2 Anatomy of Rubber wood

Rubber tree is divided in sort of softwood. The stem consists of the texture of wood which is the center of stem called "Central axis or Pith (medulla)". The next layer is wood or xylem, the next one is ring of cells or called "Cambium", then the next of cambium is soft bark which contains phloem. The next of soft bark is hard bark and the inner of hard bark, combined with soft bark, contains latex vessels that twisted on the right hand. And then, it is cork cambium and cork, respectively.[7]

The texture of the wood is fairly even with moderately straight and slightly interlocking grain. From whitish yellow when freshly cut, the wood turns to light brown as drying progresses. Latex vessels can be found with characteristic smell in some parts of the wood. The wood is soft to moderately hard with an average weight of 515 kilograms per cubic meters at 12 % moisture content. Pores on the cross section are diffused and of medium to large size, mostly solitary but sometimes in short multiples of two to three, filled with tyloses. Vessel tissues are conspicuous in radial and tangential faces and the diameter of vessel tissues are about 200 microns. Wood parenchyma are abundantly visible to the naked eye appearing as narrow, irregular and somewhat

closely spaced bands forming a net like pattern with rays. The rays of the wood are moderately broad, rather few and fairly wide spread. The pits found between the vessels and rays are half-bordered with narrow width. The length of the fibres is more than 1.0 millimeters on the average and the width is about 22 microns when it dried. The cell wall also thickness after it dried, about 2.8 microns.[8]

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

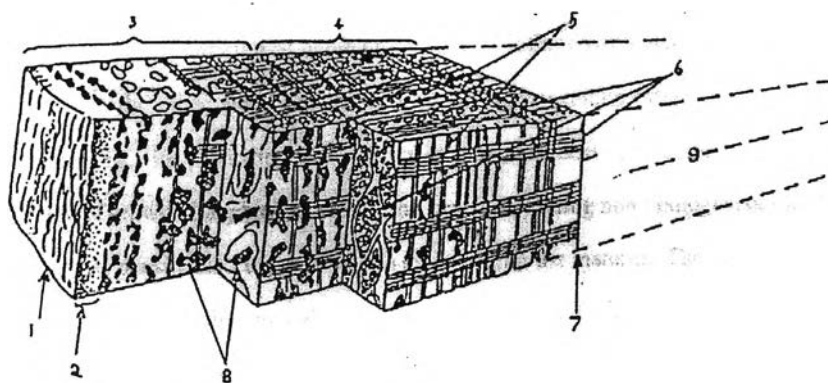


Figure 2.4 Anatomy and physiology of rubber wood

1. **Cork**
2. **Cork cambium** (between cork and hard bark)
3. **Hard bark** (consist of stone cells, parenchyma, disorganised sieve tubes, and latex vessels)
4. **Soft bark** (mainly vertical rows of sieve tubes and many latex vessels)
5. **Latex vessels**
6. **Medullary rays**
7. **Cambium**

8. Stone cells

9. Sapwood

2.2.3 Physical and Mechanical Properties of Rubber wood

Wood, when dry, has unique physical and mechanical properties in that its tensile strength, flexural strength, compressive strength, impact resistance, and hardness per unit weight are the highest of all construction materials. The hydrogen bonding, the unique helical structure of the cell walls, the combination of the linear cellulose molecules impregnated with low molecular weight extractives, and all of the varying amounts of crosslinked lignin make wood an infinitely resource.

Like the other wood species, rubber wood also exhibits orthotropicity in its properties, i.e., its properties are different and independent in the three principal direction of growth: longitudinal, radial, and tangential. Being non-homogeneous in its structure, its density also varies from site to site inside the material. The variations in properties are attributable not only to the variations in density but also to the presence of latex particles in some locations and to the predominance of tension wood. Like most of the wood species, the dynamic properties of rubber wood (i.e. mechanical behavior of rubber wood under dynamic forces) are higher than the static properties. In other words, under impact loads, rubber wood is capable of taking loads nearly twice that under slowly applied loads. However, it may be noted that the static properties of rubber wood in dry condition are higher than those in green condition.[9]

2.3 Wood Properties [10, 11]

That area of wood science concerned with the physical and mechanical properties of wood and the factors, which affect them. Since wood consists of aggregates of long tubular cells, most of which are oriented longitudinally in the tree, whereas the ray cells are oriented radially, wood is an ortho-tropic material and exhibits different physical behavior in the three main structural directions, longitudinal, radial, and tangential.

2.3.1 Density

Density is the weight or masses of a unit volume of wood, and specific gravity the ratio of the density of wood to that of water. In the metric system of measurement, density and specific

gravity are numerically identical. Determination of the density of wood in relation to that of other materials is difficult because wood is hygroscopic, and both its weight and volume are greatly influenced by moisture content. With specimens regular in shape, volume may be calculated on the basis of their dimensions. Differences among species, or samples of the same species, are due to different proportions of wood substance and void volume, and to content of extractives. Density affects the amount of moisture that wood can hold, its shrinkage, swelling, mechanical and other properties; in general, density measures the quality of wood without defects.

2.3.2 Hygroscopicity

Wood can absorb water as a liquid, if in contact with it, or in the form of vapor from the surrounding atmosphere. Though wood may absorb other liquids and gases, water is the most important. Because of its hygroscopicity, wood, either as a part of the living tree or as a material, always contains moisture. This moisture affects all wood properties. Dimensions change and decay resistance are greatly affected.

2.3.3 Shrinkage and Swelling

Wood is subject to dimensional changes when its moisture fluctuates below the fibre saturation point. Loss of moisture results in shrinkage, and gain in swelling. It is characteristic that dimensional changes are anisotropic-different in axial, radial, and tangential directions. Cell wall shrinkage is somewhat less than the volume of water desorbed.

2.3.4 Deterioration of Wood

The presence of water in wood is an essential requirement for fungal colonization and decay to occur. Wood is subject to deterioration by fungi, insects, marine organisms, fire, and other destructive agencies. By far the most important cause of wood loss is decay. Wood which is kept dry is safe from decay but as soon as a moisture content of 20% or more is attained it becomes susceptible to attack by fungi. The degree of saturation of the wood is an important factor in determining the speed and type of microbial colonization. A colonization can be seen because wood is a hygroscopic material it is affected by changes in the relative humidity or water potential of the surrounding environment. Therefore, wood decays if the conditions are suitable for growth and activity of fungi. Such conditions include favorable moisture, air, and temperature.

2.3.5 Strength [12]

Reaction wood occurs in branches and leaning tree trunks, often where there is marked eccentric growth of the trunk. In hardwoods it is present on the upper side of the trunk and is called tension wood, in softwoods it is described as compression wood and is found on the lower side of the trunk. Reaction wood impairs the quality of the timber producing severe distortion in converted timber, causing problems in machining and wood finish and showing very high longitudinal shrinkage on drying.

Tension wood in hardwoods is usually detected during conversion and seasoning and is common in mis-shaped logs. It is found usually on the side of the log with the longest radius and shows up as concentric, crescent-shaped zones aligned with the growth rings but differing in color and texture from normal wood. During drying it is prone to bowing, splitting and twisting and when sawn produces a woolly surface on longitudinally cut wood and a rough end surface on cross-cut wood because fibres are torn out of the wood by the saw which may be rapidly blunted. Tension wood is denser than normal wood and has fewer vessels with smaller diameters. In addition, thick-walled gelatinous fibres are a prominent feature in tension wood, these cells having a gelatinous or G-layer. It is an unlignified zone with low angle microfibrils which is easily separated from the rest of the secondary wall and contributes to excessive longitudinal shrinkage and expansion during drying and wetting.

Compression wood in softwoods is recognized as crescent-shaped zones of darker wood in cross-cut trunks. It is denser and harder with wider growth rings than normal wood, but like tension wood is prone to distortion and splitting due to shrinkage on drying. It has a lower cellulose and a higher lignin content than normal wood and the tracheids are rounded in cross-section rather than square to hexagonal.

In general, softwoods are more chemically resistant to acids than hardwoods because softwoods have a low pentosan concentration. Conversely, since the primary hemicellulose of hardwoods is a pentosan (xylan), the hardwoods are more susceptible to acid attack. Both low and high original pentosan content correlated well with resistance to acid degradation as measured by strength retention.

The stiffness and strength of wood decreases when the wood is heated and increases when the wood is cooled. This effect on mechanical properties is immediate and approximately linear at constant moisture content. If wood is exposed to elevated temperatures for an extended time, strength is permanently reduced. Similarly, extended exposure to a low temperature can induce permanent reductions in the mechanical properties of wood. The magnitude of permanent strength reduction depends upon moisture content, temperature, species of wood and specimen size.

The interesting technique of reinforced wood, through chemical treatment, from dimensional changes, from deterioration by the biological agencies of fungi and insect, is impregnation under pressure called impreg-wood or wood-polymer composite (WPC).

2.4 Wood-Polymer Composites (WPC)

Wood, itself a natural composite of cellulose fibers in a matrix of lignin (a phenolic polymer) and hemicellulose, lacks the consistency and uniformity of properties of a homogeneous material. To produce high performance lignocellulosic composites with uniform densities, durability in adverse environments, and high strength by using fiber technology and high performance adhesives. Wood-polymer composite (WPC) is currently being developed for use in building materials. This method is a wood impregnated with a polymerizable monomer (mainly vinyl monomer) in order to strengthen the properties of the natural wood.[13]

2.4.1 Impregnation Process

The impregnation process of wood is carried out by firstly evacuating the air from the wood vessels and cell lumens. Any type of mechanical vacuum pump is adequate if it can reduce the pressure in the apparatus to 7×10^{-3} torr or less. Experience has shown that the air in the cellular structure of most woods is removed as fast as the pressure in the evacuation vessel is reduced. After that, the vacuum pump is disconnected from the system at this point. The monomer or prepolymer containing crosslinking agents as well as catalyst, and on occasion dyes, is introduced into the evacuated chamber through a reservoir at atmospheric pressure. The wood must be weighed so that it does not float in the monomer solution. Alternatively the system can be pumped as the monomer is admitted into the evacuated vessel. After the wood is covered with monomer solution, atmospheric pressure is regained. Immediately the monomer solution begins

to flow into the evacuated wood structure to fill the void spaces. The soaking period, like the evacuation period, depends on the structure of wood. After the monomer impregnation is completed, the wood-polymer composite is removed and placed in an explosion-proof oven for curing.[14]

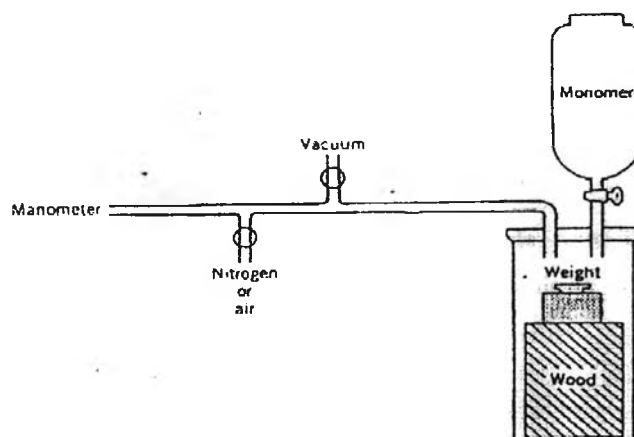


Figure 2.5 The apparatus of impregnation process

2.4.2 The Chemicals Used for Modifying Wood

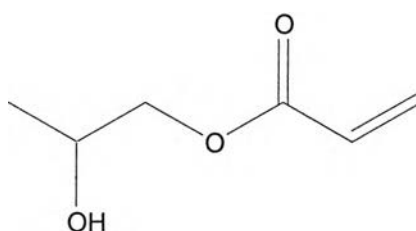
Treatment of wood to improve its physical and mechanical properties and dimensional stabilization due to moisture content and impart resistance to termites, decay, and marine organisms has been carried out via chemical modification or chemical impregnation. In chemical modification, compounds highly reactive to the hydroxyl groups of cellulose, hemicellulose, and lignin components of wood were used. Several liquid monomers such as Butylacrylate (BA), 2-Ethyl-hexylacrylate (2-EHA), and 2-Hydroxy-propylacrylate (HPA) were also incorporated into wood samples by means of chemical impregnation. Crosslinking of wood material in wood samples provides good dimensional stability to the wood-polymer composites.

The properties of acrylic ester polymers depend on the nature of alcohol radical and the molecular weight of the polymer. Poly(methylacrylate) has little or no tackiness at room temperature; it is a tough, rubbery and moderately hard polymer. Poly(ethylacrylate) is more rubberlike, considerably softer and more extensible; whereas poly(butylacrylate) is softer still and

much tackier. In the *n*-alkylacrylate series, the softness decreases through *n*-octylacrylate. Unless subjected to extreme conditions, acrylic polymers are durable and degrade slowly.

2.4.2.1 2-Hydroxy-propylacrylate (HPA)

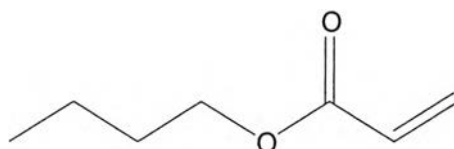
2-Hydroxy-propylacrylate (HPA) is represented by the generic formula $C_6H_{10}O_3$. It has good dimensional stability. Besides, it can improve impact strength and offers excellent chemical and heat resistance. It is used for textiles sizing agents, adhesives, flexible resin, paint and ink.



2-HYDROXY-PROPYLACRYLATE

2.4.2.2 Butylacrylate (BA)

Butylacrylate is prepared from butyl alcohol and methylacrylate. The monomer of butylacrylate is used in the manufacture of acrylate polymers and resins for textile and leather finishes. It is also used in paint formulations. Physical properties of poly-butylacrylate is a clear plastic and dielectric constant at 100 megacycle is 3.20-3.50. Poly-butylacrylate have elastic and tacky substance.

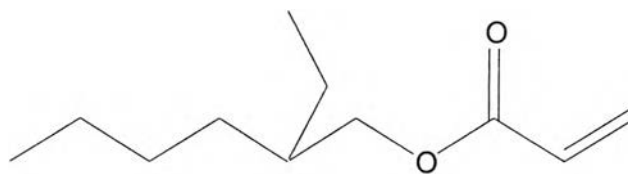


BUTYLACRYLATE

2.4.2.3 2-Ethyl-hexylacrylate (2-EHA)

Acrylic esters are represented by the generic formula $CH_2=CH-COOR$. The nature of the R group determines the properties of each ester and the polymers it forms 2-Ethyl-hexylacrylate, $CH_2=CH-COOCH_2(C_2H_5)CH(CH_2)_3CH_3$, is in this class. 2-Ethyl-hexyl acrylate responds to a

large number of initiators such as peroxides and other free radical initiators, redox initiator systems, ionic initiators, and others.



2-ETHYL HEXYL ACRYLATE

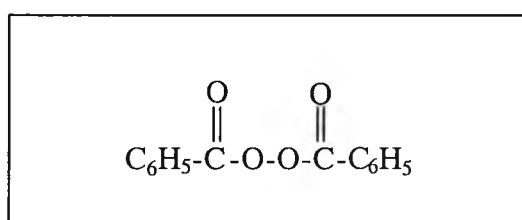
2.4.2.4 Initiators

In thermal polymerization requires a catalyst to be incorporated into the impregnation solution in order to thermally create free radical that initiate the entire polymerization process to ultimately prepare wood-polymer composites. The mechanism of production of the composite is once the free radicals are generated out of the impregnating bulk monomer with the help of the added catalyst. Peroxide initiators are chemical that cleave oxygen-oxygen bond to produce a pair of free radicals under the influence of heat or light.

2.4.2.4.1 Benzoyl Peroxide (BPO)

Benzoyl peroxide is represented by the generic formula $(C_7H_5O)_2O_2$. Its form is white paste. It is insoluble in water but miscible in alcohol and soluble in aliphatic ketone and aromatic hydrocarbon. It is an excellent catalyst for polymerization and copolymerization of resin monomer such as vinyl, aryl, styrene and unsaturated polyester of which existence of diluting agent, DOP and TCP does not obstruct polymerization.

Especially, it can be used at room temperature when it is used with accelerator such as tertiary amine (especially dimethylaniline) as curing catalyst for unsaturated polyester. It is so highly soluble in solvent as catalyst for premix that it is quite effective for moulding FRP.



The chemicals used for modifying wood must be capable of swelling the wood to facilitate penetration and can react with the hydroxyl groups in cell wall. These can improve the mechanical and physical properties. Furthermore, The chemicals should react quickly with the hydroxyl groups to yield stable chemical bonds with no by-products.

2.5 Properties of WPC [15]

Polymer composite material is known. Indeed a number of processes that deal with the treatment of wood with chemicals. Examples of these types of chemicals are monomeric 2-hydroxy-propylacrylate, butylacrylate and 2-ethyl-hexylacrylate. A polymer composite material reinforced by dispersion of a rigid polymer in a thermoplastic polymer matrix at the molecular level and a method for preparing it.

Unique properties are generally established in a polymer material due to its high-order structure. The high order structure is influenced by such a primary structure as molecular weight distribution, orientation and so on, it particularly depends largely on its molecular structure. Therefore, there have been proposed macro fiber reinforced composite materials since the past so as to overcome the limit of physical and mechanical properties, which occur naturally.

2.5.1 Mechanical Properties

Essentially the strength of wood is defined as its ability to resist loads to the point of ultimate failure although a variety of other mechanical properties including deformation under stress and elastic properties may be examined where the characteristics of stiffness and creep may be important. The mechanical or strength properties of wood measure its ability to resist applied forces that might tend to change its shape and size. Resistance to such forces depends on their magnitude and manner of application, and to various characteristics of the wood such as density, moisture content, etc. Besides, wood strength varies with direction of application of load; i.e., axially (parallel to grain), and transversely (perpendicular to grain). The mechanical properties of WPC are improved to enhance such as compressive strength is improved 4 to 5 times that of untreated wood.

2.5.2 Dimensional Stability

Many treatments have been devised to reduce swelling of wood in contact with moisture. These treatments are, in most cases, based on bulking the wood cell walls with some material to keep wood in the swollen state as long as the chemical is retained. In this swollen condition, wood cannot expand or contract further in response to contact with water. Chemicals that have been chemically reacted with cell wall components also bulk the cell wall. Permanence depends on chemical stability of the bonds formed. When the monomer was impregnated into wood and polymerized, it can increase the weight of the wood considerably. Although polymerized chemical cannot be leached by water, very little dimensional stability results from chemical treatment. The small amount of stability that is achieved may be due to some cell wall penetration by the chemical or to physical blocking of moisture (water repellency) from the cell wall.

2.5.3 Termite Resistance

Termites, which attack wood, are usually identified as either subterranean, dampwood or drywood termites. These terms describe the condition of the wood affected and the environment where attack occurs. The dampwood termites are dependent on a source of moisture which drywood termites do not require. Drywood termites are therefore able to live in wood, which is out of ground contact, the other two groups live in the soil or in wood which is in contact with soil. Thus climate factors, particularly temperature and moisture requirements, exercise the greatest influence on worldwide termite distribution and on the type of termite. Left unprotected or unpreserved, wood will decay and deteriorate anywhere from a few months to a few years, depending upon climate condition. Wood preservatives have proven to be effective in preventing the invasion of biological agents and wood destroying organisms, such as wood decay fungi, bacteria, and wood destroying insects, including termites.

2.6 Literature Reviews

The formation of wood-plastic composites is one of several methods being investigated for the dimensional stabilization of wood based materials. Several methods have been taken in attempts to reinforce mechanical or physical properties of wood product, techniques such as heat or pressure treatment, crosslamination (as in plywood), surface coating, and impregnation with various materials. The extent of improvement in mechanical and physical properties was directly related to the polymer content, the nature of the polymer, the penetration of monomers into cell

walls, the type of wood, and the processing applied. In this literature reviews are summarized as follows:

Rozman, H.D., et. al. [16] studied the wood-polymer composites of rubber wood (*Hevea brasiliensis*), prepared by impregnating the wood with methyl methacrylate (MMA), and the combinations of MMA and diallyl phthalate (MMA/DAP). Polymerization was carried out by catalytic heat treatment in the presence of catalyst. The result showed significant improvements in compressive and impact strengths, hardness, and dimensional stability (toward water) over that of the untreated rubber wood.

Fuller, B.S., et. al. [17] studied wood products impregnated with 30 to 80% of a polymerizable monomer selected from the group consisting of hexanediol diacrylate and hexanediol dimethacrylate. They found excellent indent resistance when using 0.5 to 2% of a thermally activated free radical source as a polymerization initiator for a period sufficient to achieve the desired polymer loading. The wood is heated under pressure to polymerize or cure the monomers.

Rozman, H.D., et. al. [18] prepared WPC of rubber wood by impregnating the wood with glycidyl methacrylate (GMA), combination of glycidyl methacrylate (GMA-DAP) or diallyl phthalate (DAP) alone. Polymerization was carried out by catalytic heat treatment. The results showed that WPC based on GMA exhibited greater dimensional stability. Flexural, compressive and impact properties for all the samples tested were improved, especially for those with higher chemical loading.

Mubarak, A.K., et. al. [19] prepared wood plastic composites (WPC) of simul by gamma radiation using butylacrylate (BA) and methylmethacrylate (MMA) as the monomer and methanol as the swelling agent at 9:1 (v/v) ratio. IR spectra of simul, bulk polymer of BA (or MMA) film, and WPC of different polymer loadings ranging from 18 to 115% were studied. Increase of the characteristic peak intensity at 1735 cm^{-1} (C=O vibration for acetyl groups) over that of 1620 cm^{-1} (conjugated aryl carbonyl groups) along with the increase of polymer loading of simul with the monomer indicates that the graft copolymerization took place between the monomer and the simul wood matrix.

Kasamchainanta, B. [20] prepared durianwood-polyester resins composites by impregnation under reduced pressure. Treated specimens gave significant lower water absorption, higher antishrink efficiency than natural durianwood. Modulus of elasticity, flexure stress, compression parallel to grain were improved and the density were higher than natural durianwood.

Rungvichaniwat, C. [21] prepared para rubber wood-epoxy resins composites by impregnation under reduced pressure. Treated specimens gave significant lower water absorption, higher antishrink efficiency than natural para rubber wood. Modulus of elasticity, flexure stress, compression parallel to grain were improved and specific gravity was higher than natural para rubber wood.

Sukhonphanich, A. [22] prepared rubber wood-poly(styrene-*co*-butylacrylate) and rubber wood-poly(styrene-*co*-acrylamide) composites. Physical and Mechanical properties of products were compared with natural rubber wood. Results showed that the obtained product gave modulus of elasticity, flexure stress and compression parallel to grain at about 7951-10165 MPa, 115-159 MPa and 67-90 MPa, respectively, which were better than those of natural rubber wood.

Rungsri, S. [23] prepared rubber wood composites containing poly(methylmethacrylate-*co*-acrylamide) and poly(methylmethacrylate-*co*-2-ethyl-hexylacrylate) by impregnation under reduced pressure. It found that water absorption was increased with increasing the ratio of AM and 2-EHA. Treated specimens showed better mechanical properties than those of natural rubber wood.

Boonkrai, S. [24] prepared rubber wood-composites containing poly(styrene-*co*-acrylonitrile) and poly(methylmethacrylate-*co*-acrylonitrile) by impregnation under reduced pressure. It was found that 90 phr. of styrene and 10 phr. of acrylonitrile were suitable for use in the catalyst-heat curing technique. Moreover, 80 phr. of methylmethacrylate and 20 phr. of acrylonitrile were used in the catalyst-accelerator technique. Impregnated samples resisted to fungi and termite as well as Teng and Makah-mong. Flexure stress, modulus of elasticity and compression parallel to grain could be improved better than natural rubber wood, Teng and Makah-mong.

Kaolawanich, S. [25] prepared coconut wood-composites containing poly(styrene-co-methylmethacrylate) by impregnation under reduced pressure. Polymerization was carried out by catalytic heat treatment. Physical and mechanical properties of coconut wood poly(styrene-co-methylmethacrylate) composites were improved . They were increased by 21-68% in flexure stress, 3-30% in modulus of elasticity and 24-117% in compression parallel to grain. Scanning electron microscopy was used to study the morphology of the composites.