Chapter 1

Introduction

1.1 Background

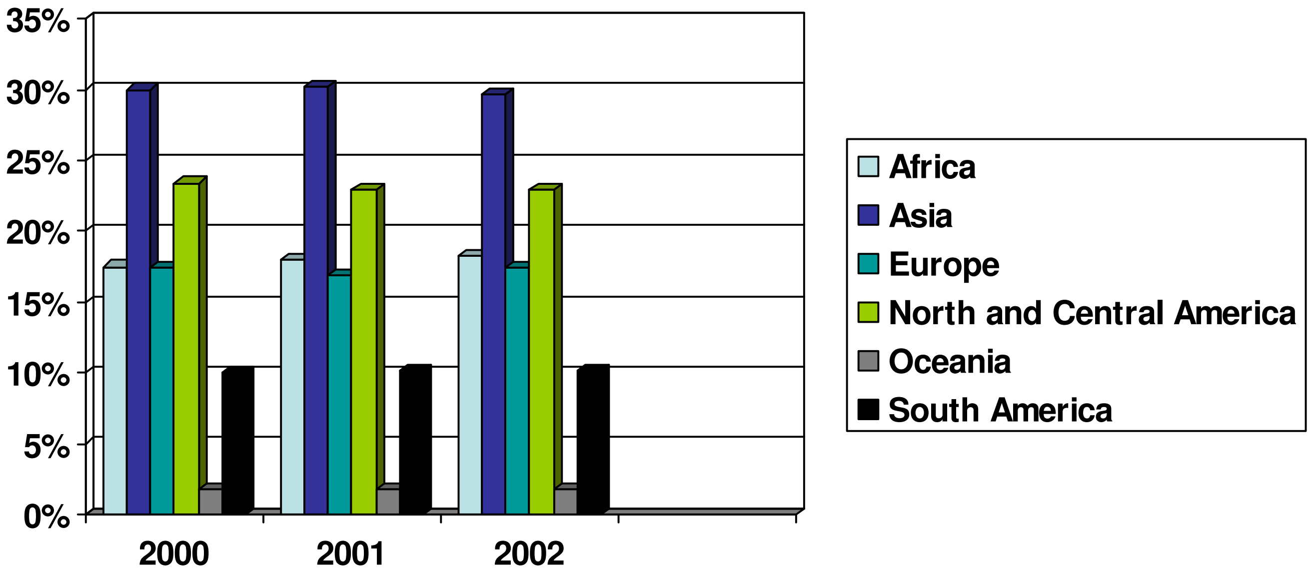
World timber trade has been established for centuries and can be regarded as a traditional part of international trade. Canada is by far the largest single exporter of forest products, alone accounting for 20% of the total export value in year 2000. USA follows second (11.5%). Finland is the largest European exporter, which is 7.5%. Indonesia becomes the largest Asia exporter (3.84%), followed by Malaysia (1.87%). The 25 countries listed in the Table 1.0, all with exports of forest products in excess of 1 billion USD, represent more than 90% of the world's export value in forest products. Table 1.0 also shows the countries with product exports greater than 1 billion USD in year 2000.

Forest resources are spread all over the globe. Some areas have very large forest resources, e.g. tropical and boreal areas. Countries with large forest resources are Brazil, Indonesia, Russia and Canada. Demand for timber products is connected to dense and fast growing populations. This is the basic driving force for trade in timber. Countries with large forest resources close to a demand and a market have an advantage compared to more remote resources. The world production of round wood for the period 2000-2002 has been approximately 3400 million cubic meters annually. Around 30% is produced in Asia. The second largest round wood producing region is North and Central America (23%), followed by Africa (18%), Europe (17%), South America (10%) and Oceania

(1.8%). Figure 1.0 shows the world round wood production by region and million cubic meters (calculated in percentage).

Table 1.0: Countries with forest product exports greater than 1 billion USD in year 2000 [1]

Country	Value, 1000 USD	Percent
Canada	29,715,800	20.45
United States of America	16,711,400	11.50
Finland	10,948,100	7.53
Sweden	9,956,570	6.85
Germany	9,949,750	6.85
France	5,907,560	4.06
Indonesia	5,578,100	3.84
Austria	4,280,470	2.95
China	3,911,350	2.69
Russian Federation	3,756,810	2.58
Belgium	3,573,740	2.46
Brazil	3,218,430	2.21
Italy	2,741,710	1.89
Malaysia	2,722,230	1.87
Netherlands	2,652,810	1.83
United Kingdom	2,195,140	1.51
Japan	1,934,200	1.33
Chile	1,890,330	1.30
Spain	1,842,830	1.27
Norway	1,831,850	1.26
Korea	1,624,250	1.12
Switzerland	1,515,780	1.04
New Zealand	1,468,530	1.01
Portugal	1,284,770	0.88
Poland	1,018,000	0.70



Total is 100%, which is 3400 million cubic meters.

Figure 1.0: World round wood production by region, million cubic meters (calculated in percentage) [1]

Therefore, forest resources are identified as one of the major supplies of renewable wood fiber in different forms [1]. However, the forest products industry traditionally uses sawmill residues and small round logs as raw materials to manufacture fiberboard; this has led to the reduction in the resources and raw materials from the existing forest as to the demands increase rapidly. Increasing import of timber and fiber supply is only a temporary solution. We must consider the prospects for developing new feedstock sources for fiberboard production. One clear potential is the use of agricultural fiber in manufacturing what have traditionally been wood-based products [2].

1.2 Wood

Wood is the most important renewable material. The management and processing of wood generate a variety of co-products and wastes throughout the wood processing chain, from its cultivation in forests, its extraction, sawing and processing to intermediate and finished products, to its recycling, incineration or final disposal. Co-products and wastes generated are residues from thinning, bark, sawdust, shavings, chips and fibers, side-cuts, wood waste and waste of intermediate products from wood and wood-based industries [3].

Wood is commonly used as a structural material for the construction of houses, bridges, railroad crossties, etc. Constant research is going on to improve the mechanical properties and durability of wood in different adverse environmental exposures [4]. From a material science standpoint, significant differences exist between production of wood and non-wood composite materials. Wood composites, also called engineering wood, are typically manufactured by first applying relatively small quantities of adhesive to wood element, mechanically forming these constituents into a loose mat structure, and then consolidating the mat under certain heat and pressure. Development of adequate strength properties requires application of compression pressure, which densifies the loose structure and results in permanent wood deformation. In contrast, non-wood composite materials consist of reinforcing elements dispersed in large quantities of resin matrix [5].

1.3 Agrowastes

Over the past decades, the utilization of forest and agricultural wastes is growing. An agricultural waste is also known as agrowastes. This fact is being mainly motivated by the increasing consumption of wood fiber-based products and reinforced composites with natural fibers. Agrowastes seem to be particularly attractive because they are sustainable, environmental friendly and economical if they could be utilized. [6].

Agrowastes are wastes generated from agriculture activities. The use of agrowaste materials as a source of raw materials in industry not only provides a renewable resource, but also generates of more economic development of rural areas [6].

The development of agrowaste reinforced composites has attracted great interests, with emphasis on the specific technological process and advantages of the composites. Modification of agrowaste materials provide a strategy for producing advanced composite materials that allow the designer to produce materials based on end use requirements within the framework of cost, renewability, recyclability, and environment consideration [7].

1.3.1 Advantages of agrowastes in composites

Agrowastes are renewable and biodegradable in nature and the resources are easily obtainable at low cost. The energy consumption is low because the temperature required for processing is normally not high. The use of natural fiber may reduce the skin irritation and respiratory diseases which could be caused by synthetic fiber dust during trimming processes. In addition, the shipping cost may be reduced due to the lighter weight of agrowastes materials [7].

1.3.2 Different types of agrowastes

Agrowastes can be broadly classified into two groups, which is fibrous and non-fibrous. Fibrous agrowastes includes sisal fiber, pineapple leaf fiber, oil palm fiber, banana fiber, coconut fiber, jute fiber etc. Non-fibrous agrowastes includes rice husk, rice hull, walnut shell, palm kernel shell etc [7].

1.4 Fiberboard

Fiberboard is a type of composite wood, fibrous-felted and homogeneous panel made from lignocellulosic fibers, combined with a synthetic resin or other suitable binder, and then bonded together under heat and pressure. Fiberboards are classified by density. Fiberboard includes medium density fiberboard (MDF) and high density fiberboard (HDF) [10,11]. A fiberboard with density between 500 kg/m^3 and 800 kg/m^3 is classified as medium density fiberboard (MDF) and a fiberboard with density greater than 800 kg/m^3 is classified as high density fiberboard [8].

Fiberboards are manufactured primarily for use as panels, insulation and cover materials in buildings and construction where flat sheets of moderate strength are required. The furniture industry is by far the dominant fiberboard market. They are also used to a considerable extent as components in doors, cabinets, cupboards and millwork. Fiberboard frequently takes the place of solid wood, plywood, and particleboard for many furniture applications. The potential use of fiberboard in other interior and exterior markets such as moldings, exterior trim and pallet decking have been explored by the industry and the market for fiberboard is fast expanding [2, 9].

1.4.1 Medium-density fiberboard

Medium-density fiberboard (MDF) is also known as Customwood or Craftwood. MDF is an engineered wood product formed by breaking down softwood into wood fibers, combining it with resin or binder and forming panels by applying high temperature and pressure. It is a building material similar in application to plywood but made up of separated fibers, not wood veneers. It is denser than normal particleboard [8, 9, 10].

Production of MDF has increased dramatically and new plants are planned worldwide. The popularity of this relatively new panel product is due to its ability to be produced in molded form, as well as in straight-edged flat panel, for a host of industrial markets. MDF is used extensively in factory-assembled and ready to assemble furniture, as well as in cabinets, drawer fronts, molding and countertops. MDF is replacing thin plywood and wet-process hardboard in the production of molded and flush door skins [11]. Figure 1.1 below shows an example of few pieces of MDF.

Figure 1.1: Picture of few pieces of medium-density board

1.4.2 High-density fiberboard (HDF)

High density fiberboard (HDF) is a wood-based panel that is composed of wood fibers bonded together with resins or binder under heat and high pressure. It is referred to as Mansonite in USA, marketed in year 1920. HDF panels are highly recommended for use in the manufacture of heavy duty flooring. Its application can be extended to institutional furniture, doors for kitchen and bedroom units, staircases, industrial shelving, moldings, exhibition stands, classroom and play area furniture, laboratory and workshop fittings, hotel restaurant and bar furniture, office furniture and components for the transportation industry requiring rigid and harsh conditions in actual service life.

High density means superior screw and fastener holding and better installation of every type of cabinet hardware. The superior stability and strength lend itself to manufacturing special shapes where impact, load and durability are concern. The range of size and thickness, ease of availability and versatility of the product itself are a specifier's dream [12]. Figure 1.2 below shows an example of HDF.

Figure 1.2: Picture of high-density board

1.5 Particle board

Particleboard can be classified into 3 categories according to the density of the particleboard. A particleboard with density less than 590 kg/m^3 is defined as low density particleboard. Density of medium density particleboard is in between 590 kg/m^3 and 800 kg/m^3. A particleboard with density greater than 800 kg/m^3 is defined as high density particleboard. Particle board is a composite wood manufactured from wood particles, such as wood chips, sawmill shavings, or even saw dust and a synthetic resin or other suitable binder, which is pressed and extruded. Particle board is **a** substitute for plywood when appearance and strength are less important than cost. However, particle board can be made more attractive by painting or by the use of wood veneers that are glued onto surfaces that will be visible [9, 10, 13]. Figure 1.3 below shows the side view of particle board.

Figure 1.3: Side view of particle board

1.6 Plywood

Plywood has been made for thousands of years; the earliest known occurrence of plywood was in ancient Egypt around 3500 BC when wooden articles were made from sawn veneers glued together crosswise.

Plywood was the first type of engineered wood to be invented. It is made from thin sheets of wood veneer, called plies or veneers. These are stacked together with the direction of each ply's grain differing from its neighbors' by 90° (cross-banding). The plies are bonded under heat and pressure with strong adhesives, usually phenol formaldehyde resin, making plywood a type of composite material. A common reason for using plywood instead of plain wood is its resistance to cracking, shrinkage, twisting or warping, and its general high degree of strength.

Plywood can be classified into two groups, which are softwood and hardwood. Softwood is typically used for construction and industrial purposes, while hardwood is commonly used in decorative industries.

Plywood is used in any application that needs high quality wooden sheet material. Plywood is also used as an engineering material for stressed skin applications. Plywood has been used in this fashion for marine and aviation applications since the WWII era. Plywood is currently used in stressed skin applications quite successfully [9, 10, 13]. Figure 1.4 shows a picture of plywood made from spruce.

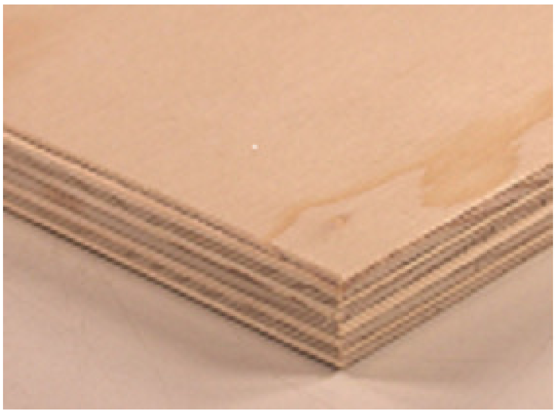


Figure 1.4: Picture of plywood made from spruce

1.7 Oriented strand board (OSB)

Oriented strand board, or OSB, or waferboard**,** is an engineered wood product formed by layering strands (flakes) of wood in specific orientations. In appearance it has a rough and variegated surface with the individual strips of around 2.5 by 15 cm (~1 inch by ~6 inches) each lying unevenly across each other in the direction of their grain.

It is manufactured from cross-oriented layers of thin, rectangular wooden strips compressed and bonded together with adhesives. The major adhesives are phenol-formaldehyde or isocyanates [14]. The layers are created by shredding the wood into strips, these are sifted and then oriented on a belt or wire cauls. The mat is made in a forming line; the layers are built up with the external layers aligned in the panel direction and internal layers cross-oriented. The number of layers placed is determined partly by the thickness of the panel.

Different qualities in terms of thickness, panel size, strength and rigidity can be imparted to the OSB by changes in the manufacturing process. OSB panels have no internal gaps or voids, and are water-resistant, although they do require additional membranes to achieve impermeability to water. The finished product has similar properties to plywood, but is uniform and cheaper. It has replaced plywood in many environments, especially the North American structural panel market. The most common uses are as sheathing in walls, floors, and roofs [9, 10, 13]. Figure 1.5 shows the picture of OSB that is made from a mixture of dried small wood chips, glue and additives.

Figure 1.5: Oriented strand board that made from a mixture of dried small wood chips, glue and additives

1.8 Chemical composition of fiberboard

Fiberboards are based on wood or other lignocellulosic fibers held together by an adhesive bond. Therefore, fiberboard consists of cellulose, hemicelluloses, lignin, pectin and starch [15, 16]. Table 1.1 shows the chemical composition of fiberboard.

Table 1.1: Composition of wood fiber [15, 16]

Composition	Hardwood (%)	Softwood (%)
Cellulose	40-50	40-45
Hemicellulose	25-35	25-30
Lignin	20-25	25-35
Pectin	1-2	1-2
Starch	0.01	0.01

1.8.1 Cellulose

Cellulose is a polysaccharide derived from β-glucose and can be represented as $(C_6H_{10}O_5)_n$. Each glucose unit contains three hydroxyl groups, composed of two secondary alcohol groups, which are arranged in position 2, 3 and 6 respectively. Hence, the glucose units are linked together by 1,4-glycosidic oxygen bonds [17]. The primary cell wall of green plants is made of cellulose; the secondary wall contains cellulose with variable amounts of lignin and hemicellulose. Lignin and cellulose, considered together, are termed "lignocellulose". Cellulose is straight chain, crystalline and resistant to hydrolysis [18]. Figure 1.6 shows the chemical structure of cellulose as polymer of β-D-glucose.

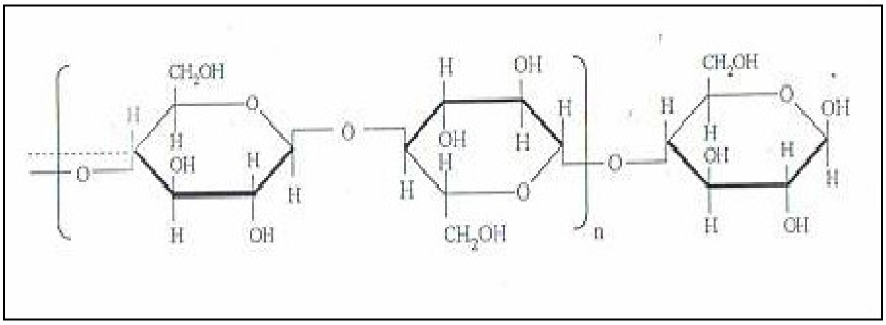


Figure 1.6: Cellulose as polymer of β-D-glucose [16]

1.8.2 Hemicellulose

Hemicellulose, a polysaccharide present in almost all cell walls along with cellulose in plants. Hemicellulose contains many different sugar monomers, which include xylose, mannose, galactose, rhamnose and arabinose. Hemicellulose consists of shorter chains but it is branched and has a random, amorphous structure with little strength. It is easily hydrolyzed by dilute acid or base. Hemicelluloses are imbedded in the cell walls of plants, sometimes in chains that form a 'ground' - they bind pectin to cellulose to form a network of cross-linked fibres [15, 16]. Figure 1.7 shows the structure of hemicellulose.

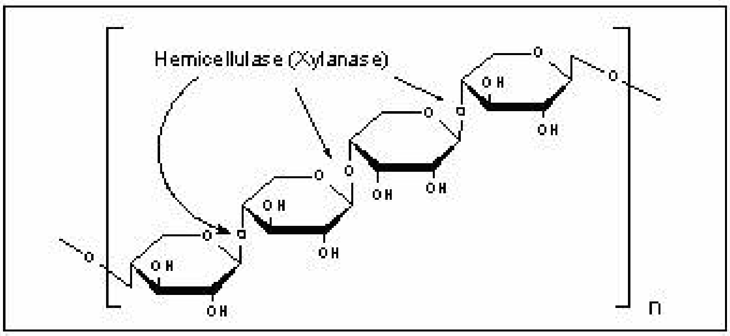


Figure 1.7: Structure of hemicellulose [19]

1.8.3 Lignin

Lignin is a large, cross-linked macromolecule. It has a molecular weight of approximately 11,000 [20]. It is relatively hydrophobic and aromatic in nature. Lignin fills the spaces in the cell wall between cellulose, hemicellulose and pectin components. It is covalently linked to hemicellulose. It also forms covalent bonds to polysaccharides and thereby crosslinks different plant polysaccharides. The crosslinking of polysaccharides by lignin is an obstacle for water absorption to the cell wall. Thus, lignin is more hydrophobic and insoluble in water [20]. Figure 1.8 represents the chemical structure of lignin.

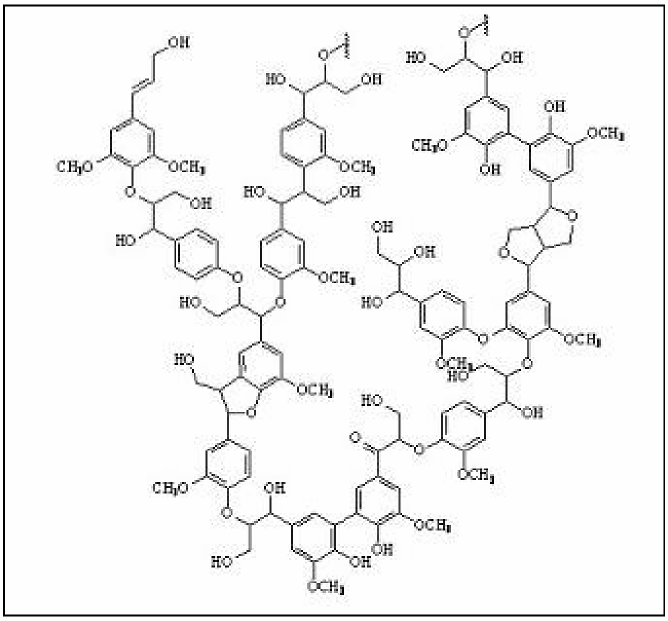


Figure 1.8: Structure of lignin [21]

1.8.4 Pectin

Pectin, a white to light brown powder, is a heterosaccharide derived from the cell wall of higher terrestrial plants. Naturally, pectin is in the form of complex and it helps to bind cells together and regulates water in the plant. Industrially, it is mainly used in food as a gelling agent in jams and jellies. Today it is also used in fillings, sweets, as a stabiliser in fruit-juices and milk-drinks and as a source of dietary fiber in foods [22]. Figure 1.9 shows the chemical structure of pectin.

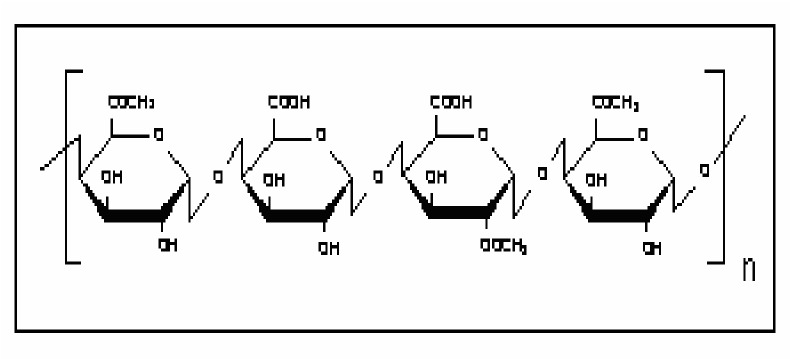


Figure 1.9: Structure of pectin [19]

1.8.5 Starch

Starch is a complex carbohydrate which is insoluble in water; it is used by plants as a way to store excess glucose. Starch contains a mixture of two molecules: amylose and amylopectin. Usually these are found in a ratio of 30:70 or 20:80, with amylopectin found in larger amounts than amylose. Starch is by far the most important of the polysaccharides and is often found in fruits, seeds, rhizomes or tubers of plants. The major resources for starch production and consumption worldwide are rice, wheat, corn and potatoes [23]. Figure 1.10 represents the chemical structure of starch.

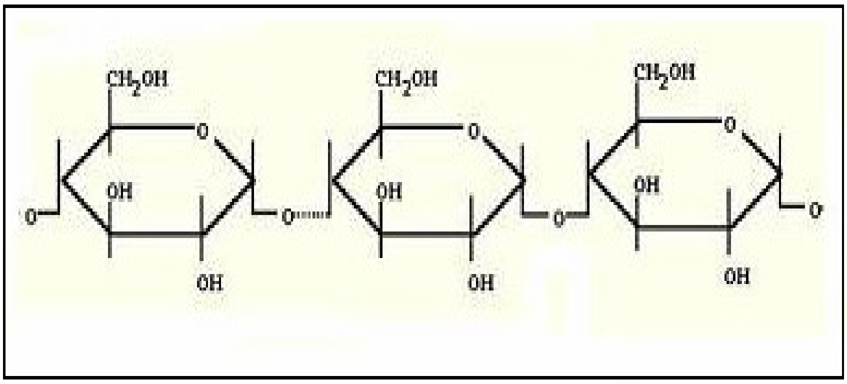


Figure 1.10: Structure of starch [24]

1.9 Binder of wood-based composite

In general, the adhesive that is applied on wood-based composite can be classified into two groups which are natural based and synthetic based. Natural based adhesive is synthesized from animals or plants. Caseine and blood albumens are some of the examples of animal adhesives, whereas lignocellulosic is an example of plant adhesive.

On the other hand, synthetic adhesives are mainly derived from petrolchemicals and can be classified as thermosetting and thermoplastic types. Thermoplastic adhesives are more commonly used in automated production because they only need the application of heat and pressure to process. Common examples are polypropylene (PP), polyethylene (PE) etc. Thermosetting adhesives for fiberboards include urea-formaldehyde resins (UF), phenol-formaldehyde resins (PF), melamine-formaldehyde resins (MF), methylene diphenyl diisocyanate (MDI) and polyurethane adhesive [25, 14].

1.9.1 Urea-formaldehyde (UF)

Urea-formaldehyde (also known as urea-methanal) is a thermosetting resin, made from urea and formaldehyde, heated in the presence of a mild base such as ammonia or pyridine. These resins are low-cost, very rapid cure, not water resistant and light colour and commonly used in adhesives for wood composites, finishes and molded objects. UF resin's attributes include high tensile strength and high flexural modulus, low water absorption, higher surface hardness, higher elongation at break and higher volume resistance [26].

1.9.2 Phenol-formaldehyde (PF)

Phenol formaldehyde (PF) polymers are the oldest class of synthetic polymers, having been developed at the beginning of the 20th century. These resins are widely used in both laminations and wood composites such as OSB, softwood and plywood because of their outstanding durability, which is derived from their good adhesion to wood, the high strength of the polymer and the excellent stability of the adhesive [27].

1.9.3 Melamine formaldehyde (MF)

Melamine formaldehyde adhesive is made from the polymerization of melamine and formaldehyde. MF is often used to saturate decorative papers which are directly laminated onto particle board and is frequently used in ready-to-assemble furniture and inexpensive kitchen cabinets. The limitation of the MF adhesives is their high cost due to the cost of the melamine[28].

1.9.4 Diphenylmethane-4,4-diisocyanate (MDI)

Diphenylmethane-4,4-diisocyanate (MDI) is an aromatic diisocyanate. It is widely used because of its better water resistant and does not contain formaldehyde and also its reactivity with groups containing reactive hydrogen which allows great flexibility in the types of products as it can self-polymerize or react with many monomers. MDI is reacted with a polyol in the manufacture of polyurethane [29].

1.9.5 Polyurethane (PU) adhesive

Polyurethane adhesive is widely used in coatings. PU adhesive can be either one-or-two component systems, which is depends on the application. The one-component system is a functionalized polymer that has remaining isocyanate groups. These groups will react with moisture causing the generation of amines that react with other isocyanate groups to form the backbone and crosslinking connections. Two-component system has an isocyanate portion and an isocyanate reactive portion. To obtain good wetting, the components need to be low molecular weight or a solvent needs to be added to reduce the viscosity for good wetting. PU adhesive is commonly used in many other bonding markets due to their good strength, flexibility, impact resistance and ability to bond many substrates [25, 29].

1.10 Palm kernel oil

Malaysia is the largest producer of palm oil in the world, with an output of more than 10 million tonnes per year. The palm oil products are well accepted by food manufacturers and consumers worldwide, such as to produce cooking oil, used in manufacture of special fats and margarines. They can be used to some extent in shortenings and vanaspati. Palm kernel oil (PKO) is derived from the flesh of the kernel while palm oil is extracted from the mesocarp of the palm fruit. Palm kernel oil can be separated into palm kernel olein and palm kernel stearin. The major fatty acid in palm kernel oil is lauric acid. The characteristics of crude palm oil and palm kernel oil are listed in Table 1.2. The fatty acid composition and chemical characteristics of palm kernel oil are shown in Table 1.3 [30, 31, 32]

Table 1.2: Characteristics of crude palm oil and palm kernel oil [30, 31, 32].

	Crude palm oil	Palm kernel oil
Free fatty acid (%)	3.79	3.08
Peroxide value (meq/kg)	2.80	0.30
Anisidine value	3.30	1.50
Carotenoids (ppm)	>600	7.20
DOBI (Deterioration Of Bleachability Index)	2.70	-
Iodine value	52.50	18.10
Saponification value	197	246
Moisture and impurities (%)	0.25	0.20
Unsaponifiable matter (%)	0.70	0.50
Melting point (°C)	36.50	26.00
Copper (ppm)	0.12	-
Iron (ppm)	4.20	-
Phosphatides (ppm)	694	200

Table 1.3: Fatty acid composition and chemical characteristics of palm kernel oil [30, 31, 32].

	Palm kernel oil	
Number of samples	118	
Fatty acid composition (% by weight)	Mean	Range
C6:0	0.3	0.1-0.5
C8:0	4.2	3.4-5.9
C10:0	3.7	3.3-4.4
C12:0	48.7	46.3-51.1
C14:0	15.6	14.3-16.8
C16:0	7.5	6.5-8.9
C18:0	1.8	1.6-2.6
C18:1	14.8	13.2-16.4
C18:2	2.6	2.2-3.4
C20:0	Not detected	Not detected
Others	0.1	Trace-0.9

1.11 Palm fiber

In Malaysia, empty fruit bunches (EFB) are one of the biomass materials produced from palm oil industry. The production of EFB is estimated to be around 2.8-3.0 million tonnes annually. Besides EFB, the waste products from palm oil industry are extracted seeds, oil palm fronds (OPF) and oil palm trunks (OPT). Many studies have been carried out on the utilization of these waste fibers such as in particleboard, medium density fiberboard, pulp and other wood composites. In general, utilization of these lignocellulosic materials has been attributed to several advantages which are low density, deformability, less abrasive to equipment, biodegradability and low cost [30, 33].

1.12 Scope of study

In this project, palm kernel oil was chemically converted to polyols and subsequently into a PU binder for making fiberboards. The project is divided into two main sections. First is the synthesis of the palm based polyester polyols. Second is to convert palm fiber into fiberboard by using palm oil based polyester polyols in combination with diphenylmethane diisocyanate (MDI) followed by characterization of the palm fiberboard.