Chapter one

Introduction

It would be difficult to imagine our modern world without using plastics. Today plastic plays an important role in our daily life due to their relatively low cost, ease of manufacture, versatility and imperviousness. Plastic are used in an enormous and expanding range of product, from paperclips to spaceship. They have already displaced many traditional materials, such as wood, stone, lather, metal, glass and ceramic.

There are two types of plastic: thermoplastics and thermosetting polymers. Thermoplastics are the plastic that do not undergo chemical change in their composition when heated and can be moulded again and again, examples are polyethylene (PE), polystyrene (PS), polypropylene (PP), and poly vinyl chloride (PVC). Thermosets can be melt and take shape once after they have solidified, they stay solid examples are phenolic and unsaturated polyester. Also can be classified by its various physical properties, such as density, tensile strength, glass transition temperature and resistance to various chemical products.

. Nowadays, we are using materials with specific properties to give a good quality product with low cost, this material produced by combination of two different materials with different properties (chemical or physical) during reaction under specific conditions and additives (filler, lubricant, stabilizer and coupling agent). This material called composite. Composites can be defined as materials that consist of two or more chemically and physically different phases separated by a distinct interface. Composite can be made by mixing of two plastic materials with each other or using of plastic with other materials such as wood or metal

For example of it wood plastic composites (WPCs) which contains polymer plastic (pure or recycle) such as PVC, PE, PP and wood of different shapes which are used to produce window/door profiles, railing, siding and furniture. . In general, manufacturing of WPCs are a two-step process, combination of wood and thermoplastic such as high density polyethylene (HDPE), low density polyethylene (LDPE) and polyvinyl chloride (PVC) are mixed together dough-like-consistency called compounding. Mixing can be handled by either batch or continuous Process. In addition to the main ingredient wood with grain size ranging from 20 to 60 mesh, plastic coupling agents, stabilizer, foaming agents or dyes also are added to enhance properties of the final product for a particular use. There are three common forming methods for WPC. Extrusion method, which forces molten composite through a die or injection molding method, molten composite is forced into a cold mold and the third one presses molten composite between mold halves. Most of the physical and mechanical properties of WPC depend mainly on the interaction developed between wood and thermoplastic material.

In this thesis I am dealing with a sample from moawia's factory for furniture in Khartoum north to study the mechanical properties such as density test, absorption test, hardness test, impact test and burning test in Sudan University for science and technology. Also the different between types of wood which was found in the Sudan and what the best type for using in this compounding to give a proper mechanical properties and having low cost.

1.2Research objectives:

- To know what are the WPCs, how it produced and the properties of it.
- To make sure there is a good quality of product made from it.
- To study the other types of wood in Sudan to select the best one.

1.3 Research problem:

- Lack of knowledgment about this compounding and its product.
- Lack of laboratories to study the properties.
- Lack of equipment that assist in the chemical process.
- Lack of factories to take more products to study.

1.4 Research methodology:

The methodology of this study started by identifying the problem statement, literature review, data collection, analysis of result by excel program, discussion of result, conclusion and recommendations.

Chapter one: Introduction

Chapter two: Literature review

Chapter three: Material and method

Chapter four: Result and discussion

Chapter five: Conclusion and recommendation

Chapter two

Literature review

a) History of wood composite plastic WPC

The development of plastics accelerated with Charles Goodyear's discovery of vulcanization as a route to thermoset materials derived from natural rubber. Many storied materials were reported as industrial chemistry was developed in the 1800s. In the early 1900s, Bakelite, the first fully synthetic thermoset was reported by Belgian chemist Leo Baekeland. In 1933, polyethylene was discovered by Imperial Chemical Industries (ICI) researchers Reginald Gibson and Eric Fawcett.[3] After the First World War, improvements in chemical technology led to an explosion in new forms of plastics; mass production began around the 1940s and 1950s.[4] Polypropylene was found in 1954 by Giulio Natta and began to be manufactured in 1957.[3] Among the earliest examples in the wave of new polymers were polystyrene (PS), first produced by BASF in the 1930s,[3] and polyvinyl chloride (PVC) was accidentally discovered at least twice in the 19th century, first in 200 by French chemist Henri Victor Regnault and then in 1872 by German chemist Eugen Baumann. On both occasions the polymer appeared as a white solid inside flasks of vinyl chloride that had been left exposed to sunlight. In the early 20th century the Russian chemist Ivan Ostromislensky and Fritz Klatte of the German chemical company Griesheim-Elektron both attempted to use PVC in commercial products, but difficulties in processing the rigid, sometimes brittle polymer blocked their efforts. Waldo Semon and the B.F. Goodrich Company developed a method in 1926 to plasticize PVC by blending it with various additives. The result was a more flexible and more easily processed material that soon achieved widespread commercial use.

Until the 1990s, wood was the material of choice for deck construction. However, new products, composites, began to emerge at this time. These new products offered the look and workability of wood, but they were more water resistant and required less maintenance. Over time, these lower maintenance decking options increased in popularity. Although the majority of decks are still built of pressure treated pine, redwood, cedar or mahogany, use of composite woods has increased as outdoor decks and living areas have become popular as home features.[1]

A 2011 discovery in the Canadian province of New Brunswick uncovered the earliest known plants to have grown wood, approximately 395 to 400 million years ago.[3] People have used wood for millennia for many purposes, primarily as a fuel or as a construction material for making houses, tools, weapons, furniture, packaging, artworks, and paper.

In the past ten years wood polymer composite (WPC) has become a state of the art commercial product with a growing market potential in the area of building, construction, and furniture. The market share of WPC in the area of automotive is also increasing in Europe and Asia. Although WPC has a long history in Europe from the beginning of the twenty-first century, the main commercialization has happened only since the early 1990s. A major manufacturing initiative was undertaken by small and medium enterprises (SMEs) in North America in the mid-1990s that resulted in a fully commercialized decking product for the building industry. Since then, many other innovative products have been commercialized in the United States and Canada. A major market trend is now to expand the product range in construction with enhanced mechanical performance and durability. In recent years we have seen that WPC products are slowly penetrating the European market, in automotive applications, furniture, and in building products.

On the research and development front WPC has gained significant popularity as evidenced by a threefold to fourfold increase in international symposia and workshops in the past five years. Major growth in the technology is coming from equipment design, process formulation and product design.

2.1 Wood composite material:

Wood plastic composites (WPCs) are roughly 50:50 mixtures of thermoplastic polymers and small wood particles. The wood and thermoplastics are usually compounded above the melting temperature of the thermoplastic polymers and then further processed to make various WPC products. WPC can be manufactured in a variety of colors, shapes, sizes and with different surface textures. Depending on the processing method, WPCs can be formed into almost any shape and thus are used for a wide variety of applications, including windows, door frames, and interior panels in car, railing, fences, landscaping timbers, cladding, siding, park benches, molding and furniture.

2.2What are WPC?

To understand wood plastic composite (WPC) adequately, we must first understand the two main constituents. Though both are polymer based, they are very different in origin, structure and performance. In WPCs, a polymer matrix forms the continuous phase surrounding the wood component. These matrix polymers are low typically low cost commodity polymers that flow easily when heated, allowing for considerable processing flexibility when wood is combined with them. These polymers tend to shrink and swell with temperature but absorb little moisture and can be effective barriers to moisture intrusion in a well-designed composite.

1) Wood

Wood is a hard, fibrous structural tissue found in the stems and roots of trees and other woody plants. It has been used for thousands of years for both fuel and as a construction material. It is an organic material, a natural composite of cellulose fibers (which are strong in tension) embedded in a matrix of lignin which resists compression. It is sometimes defined as only the secondary xylem in the stems of trees,[5] or it is defined more broadly to include the same type of tissue elsewhere such as in tree roots or in other plants such as shrubs.[citation needed] In a living tree it performs a support function, enabling woody plants to grow large or to stand up by themselves. It also mediates the transfer of water and nutrients to the leaves and other growing tissues. Wood may also refer to other plant materials with comparable properties, and to material engineered from wood, or wood chips or fiber.

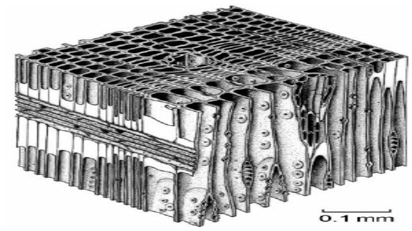
The Earth contains about one trillion tonnes of wood, which grows at a rate of 10 billion tonnes per year. As an abundant, carbon-neutral renewable resource, woody materials have been of intense interest as a source of renewable energy. In 1991, approximately 3.5 billion cubic meters of wood were harvested. Dominant uses were for furniture and building construction.[6]

The efficient structure and anatomy make it a stiff, strong, tough and lightweight material that can efficiently perform functions such as moisture transport that are critical for survival of the tree.

From a polymer composite standpoint, wood is less expensive, stiffer and stronger than many commodity synthetic polymers, making it a candidate for filling and reinforcing them. We will first discuss the structure, anatomy and types of wood.

- **Wood anatomy**

As with most natural materials, the anatomy of wood is complex. Wood is porous, fibrous, and anisotropic. Wood is often broken down into two broad classes: softwoods and hardwoods, which are actually classified by botanical and anatomical features rather than wood hardness. Figures (2.1) and (2.2) are schematics of a softwood and hardwood, respectively, showing the typical anatomies of each wood type. Softwoods (or gymnosperms) include such species as pines, firs, cedars, and spruces; hardwoods (or angiosperms) include species such as the oaks, maples, and ashes.



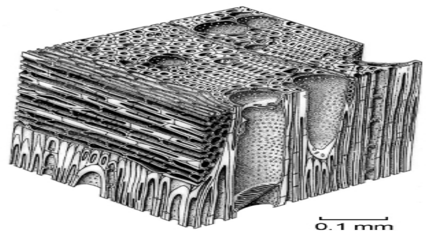


Fig (2.1) Schematic of softwood. Fig (2.2) Schematic of a hardwood.

Wood is primarily composed of hollow, elongated, spindle-shaped cells (called tracheids or fibers) that are arranged parallel to each other along the trunk of the tree (Miller, 1999). The lumen (hollow center of the fibers) can be completely or partially filled with deposits, such as resins or gums, or growths from neighboring cells called tyloses (Miller, 1999). These fibers are firmly cemented together and form the structural component of wood tissue. The length of wood fibers is highly variable but average about 1 mm (1/25 in.) for hardwoods and 3±8 mm (1/8 to 1/3 in.) for softwoods (Miller, 1999). Fiber diameters are typically 15±45 "m.

- **Chemical constituents**

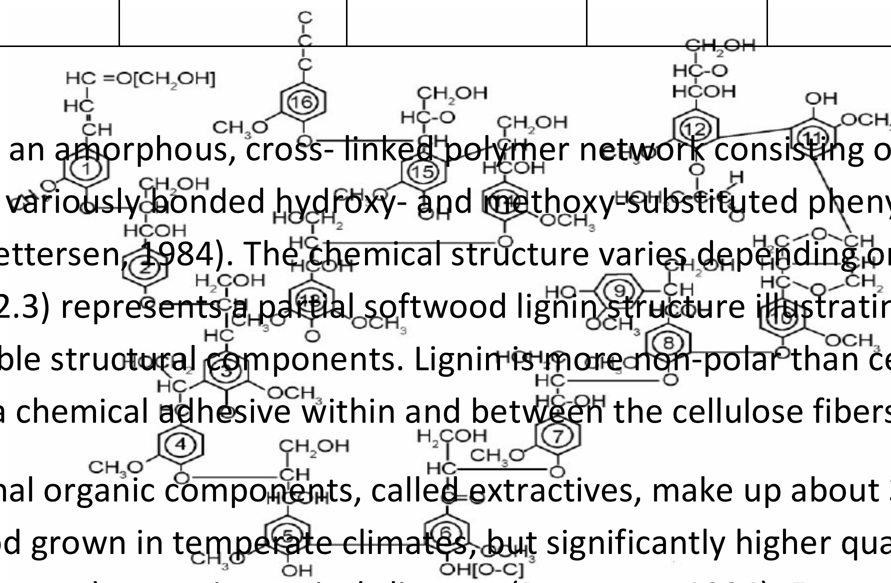
The wood substance itself is a complex, three-dimensional, polymer composite made up primarily of cellulose, hemicellulose, and lignin (Rowell, 1983). These three hydroxyl-containing polymers are distributed throughout the cell wall. The chemical compositions of selected woods are shown in Table (2.1).

Cellulose varies the least in chemical structure of the three major components. It is a highly crystalline, linear polymer of anhydroglucose units with a degree of polymerization (n) around 10 000 (Fig. 1.8). It is the main component providing the wood's strength and structural stability. Cellulose is typically 60± 90% crystalline by weight and its crystal structure is a mixture of monoclinic and triclinic unit cells (Imai and Sugiyama, 1998; Wada et al., 1994). Hemi- celluloses are branched polymers composed of various 5- and 6-carbon sugars whose molecular weights are well below those of cellulose but which still contribute as a structural component of wood (Pettersen, 1984).

Table (2.1): Approximate chemical composition of selected woods from

Petterson (1984)

Species	Celluloses	Hemicellulose [b]	Lignin [c]	Extractives [d]	Ash
Ponderosa pine	41	27	26	5	0.5
Loblolly pine	45	23	27	4	0.2
Incense cedar	37	19	34	3	0.3
Red maple	47	30	21	2	0.4
White oak	47	20	27	3	0.4
Southern red oak	42	27	25	4	0.4



Lignin is an amorphous, cross- linked polymer network consisting of an irregular array of variously bonded hydroxy- and methoxy-substituted phenyl- propane units (Pettersen, 1984). The chemical structure varies depending on its source. Figure (2.3) represents a partial softwood lignin structure illustrating a variety of possible structural components. Lignin is more non-polar than cellulose and acts as a chemical adhesive within and between the cellulose fibers.

Additional organic components, called extractives, make up about 3±10% of the dry wood grown in temperate climates, but significantly higher quantities are found in wood grown in tropical climates (Pettersen, 1984). Extractives include substances such as fats, waxes, resins, proteins, gums, turpenes, and simple sugars. Many of these extractives function in tree metabolism and act as energy reserves or defend against microbial attack. Though often small in quantity, extractives can have large influences on properties such as color, odor, and decay resistance (Pettersen, 1984). Small quantities (typically 1%) of inorganic matter, termed ash, are also present in wood grown in temperate regions.

Cellulose forms crystalline micro fibrils held together by hydrogen bonds and then cemented to lignin into the wood fiber cell wall. The micro fibrils are aligned in the fiber direction in most of the cell wall, winding in a helix along the fiber axis. The angle between the micro fibril and fiber axes is called the micro fibril helix angle. The micro fibril helix angle is typically 5±20ë for most of the cell wall (Parham and Gray, 1984) and varies depending upon many factors, including species and stresses on the wood during growth.

Fig (2.3) A partial softwood lignin structure (Pettersen, 1984).

- ## <u>Types of wood:</u>

Wood is often broken down into two broad classes: softwoods and hardwood, which actually classified by botanical and anatomical features rather than hardness.[12]

i. <u>Hardwood:</u>

OAK: Oak is the most widely used hardwood. There are more than 60 species of oak grown in the U.S., which can be separated into two basic varieties; white and red. The red variety is also known as black oak (a reference to its bark).

Properties: Oak is a heavy, strong, light colored hardwood.

Uses: Oak is the most popular wood used to craft American and English country designs. It is also used for Gothic and William & Mary reproductions, as well as many transitional and contemporary pieces.

MAPLE: There are 115 species of maple. Only 5 commercially important species grow in the U.S. Two of the five are hard rock maple and sugar maple.

Properties: Maple is so hard and resistant to shocks that it is often used for bowling alley floors.

Uses: Maple is used extensively for American colonial furniture, especially in medium and lower priced categories. It can also be stained to simulate cherry wood, which it resembles.

MAHOGANY: Mahogany, also known as Honduras mahogany is a tropical hardwood indigenous to South America, Central America, Africa and Sudan. There are many different grades and species sold under this name, which vary widely in quality and price.

Properties: Mahogany is strong, with a uniform pore structure and poorly defined annual rings. It has a reddish - brown color and may display stripe, ribbon, broken stripe, rope, ripple, and mottle, fiddle back or blister figures. Crotch mahogany figures are widely used and greatly valued. Mahogany is an excellent carving wood and finishes well.

Uses: Mahogany is used extensively in the crafting of Georgian, Empire and Federal reproduction furniture.

CHERRY: Cherry is grown in the Eastern half of the U.S. It is sometimes called fruitwood. The term fruitwood is also used to describe a light brown finish on other woods.

Properties: A moderately hard, strong, closed grain, light to red-brown wood, cherry resists warping and checking. It is easy to carve and polish.

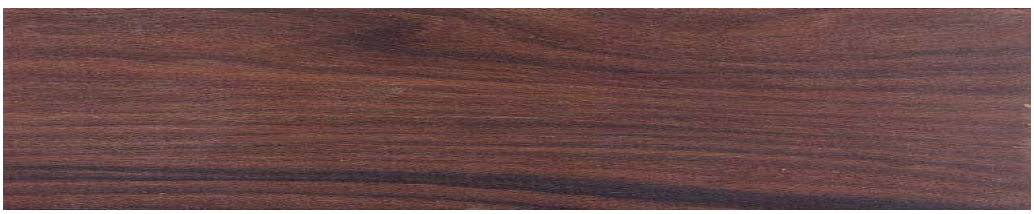
Uses: Cherry veneers and solids are used in a variety of styles. Cherry has been called New England mahogany and is often used to craft 18th century, Colonial and French Provincial designs.

WALNUT: Walnut is one of the most versatile and popular cabinet making woods. It grows in Europe, America and Asia. There are many different varieties.

Properties: Walnut is strong, hard and durable, without being excessively heavy. It has excellent woodworking qualities, and takes finishes well. The wood is light to dark chocolate brown in color with a straight grain in the trunk.

Uses: Walnut is used in all types of fine cabinet work, especially 1 8th century reproductions.

ROSEWOOD: Very hard and has a dark reddish brown color. It is fragrant and close grained. It is hard to work and takes high polish. Used in musical instruments, piano cases, tool handles art projects, veneers and furniture.



TEAK: True teak is indigenous to Southeast Asia, but similar wood species also grow in Africa in Sudan.

Properties: Teak is a yellow to dark brown hardwood which is extremely heavy, strong and durable.

Uses: Scandinavian modern and oriental furniture styles are often crafted of teak.

ii. Softwood:

PINE: Pine is softwood which grows in most areas of the Northern Hemisphere. There are more than 100 species worldwide.

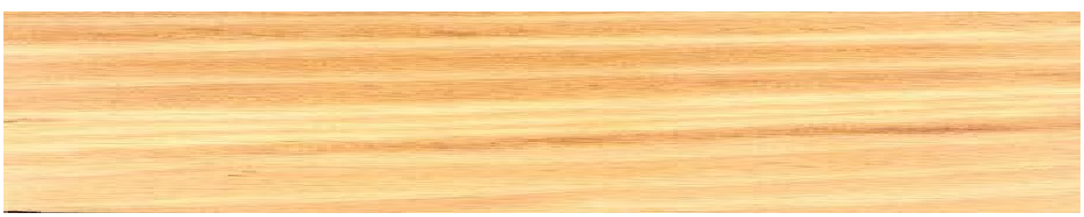
Properties: Pine is a soft, white or pale yellow wood which is light weight, straight grained and lacks figure. It resists shrinking and swelling. Knotty pine is often used for decorative effect.

Uses: Pine is often used for country or provincial furniture. Pickled, whitened, painted and oil finishes are often used on this wood.

ASH: There are 16 species of ash which grow in the eastern United States. Of these, the white ash is the largest and most commercially important.

Properties: Ash is a hard, heavy, ring porous hardwood. It has a prominent grain that resembles oak, and a white to light brown color.

Uses: Ash is widely used for structural frames and steam bent furniture pieces. It is often less expensive than comparable hardwoods.



HICKORY: There are 15 species of hickory in the eastern United States, eight of which are commercially important.

Properties: Hickory is one of the heaviest and hardest woods available. Pecan is a species of hickory sometimes used in furniture. It has a close grain without much figure.

Uses: Wood from the hickory is used for structural parts, especially where strength and thinness are required.

BEECH: The American beech is a single species which grows in the eastern half of the United States.

Properties: Beech is a hard, strong, heavy wood with tiny pores and large conspicuous medullary rays, similar in appearance to maple.

Uses: it is often used for frames, a variety of bent and turned parts.

REDWOOD: Indigenous to the Pacific United States, redwood trees grow to more than 300 feet tall and 2,500 years old.

Properties: The best quality redwood comes from the heartwood which is resistant to deterioration due to sunlight, moisture and insects.

Uses: It is used to craft outdoor furniture and decorative carvings. Redwood burls have a "cluster of eyes" figure. They are rare and valuable.

FIR: Works easy and finishes well. Uniform in texture and low resistance to decay.

Uses: in furniture, doors, frames, windows, plywood, veneer, general millwork and interior trim.

SPRUCE: Strong and hard. Finishes well and has low resistance to decay. Has moderate shrinkage and light in weight.

Uses: for masts and spars for ships, aircraft, crates, boxes, general millwork and ladders.

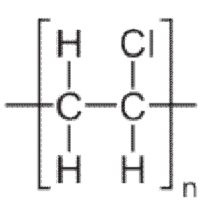
2) Plastic:

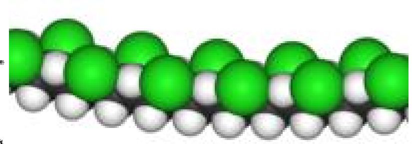
Plastics are typically polymers of high molecular mass, and may contain other substances to improve performance and/or reduce production costs. Monomers of plastic are either naturel or synthetic organic compounds.

There are two types of plastic: thermoplastics and thermosetting polymers. Thermoplastics are the plastic that do not undergo chemical change in their composition when heated and can be moulded again and again, examples are polyethylene (PE), polystyrene (PS), polypropylene (PP), and poly vinyl chloride (PVC). Thermosets can be melt and take shape once after they have solidified, they stay solid examples are phenolic and unsaturated polyester.

- **polyvinyl chloride (PVC)**

Polyvinyl chloride (PVC, commonly called “vinyl”) is the one of the thermoplastic polymers has side chains incorporating chlorine atoms, which form strong bonds. PVC in its normal form is stiff, strong, heat and weather resistant, and cannot be processed on its own due to its very low thermal stability and high melt viscosity. Therefore, it is necessary to combine with the polymer a number of suitable additives using plasticizers, into flexible materials, usually called (PVC-P) or without plasticizer, for rigid (PVC-U) to give a wide and varied range of properties to satisfy many different end-use applications like electrical wires, pipes, garden houses, shoes, bags and sheets.





The repeating unit of PVC   Space-filling model of a part of a PVC chain

Figure (2.4): The repeating unit and part model of chain

- **Properties**

The properties for PVC are usually categorized based on rigid and flexible PVCs shown in table (2.2).[3]

Table (2.2): shown the physical properties for PVC

Property	Rigid PVC (U-PVC)	Flexible PVC (P-PVC)
Density [g/cm3]	1.3-1.45	1.1-1.35
Thermal conductivity [w/(m.k)]	0.14-0.28	0.14-0.17
Yield strength [Mpa]	31-60	10-25

Table (2.3): Mechanical properties

Elongation at break	20-40%
Glass temperature	82 °C[3]
Melting point	100–260 °C[3]
Specific heat (c)	0.9 kJ/(kg•K)
Water absorption (ASTM)	0.04–0.4

2.3Advantages:

WPCs offer a number of potential benefits. The presence of wood in a plastic matrix can result in a stiffer and lower cost material then if plastic alone was used. Also the compression properties (resistance to crushing) for most WPCs are superior to that of wood loaded perpendicular to the grain. The plastic in the product is not subject to water absorption or biological attack, so the WPC can have lower maintenance requirements than solid wood. WPC lumber will not warp, splinter or check. The high moisture resistance of WPCs (water absorption of 0.7%) is a direct result of structure.

WPCs offer great flexibility in the shapes and colors of the materials produced. Materials usage can be also being reduced through the engineering of special shapes –e.g., hollow – core decking boards.

2.4Disadvantages:

The wood component within the WPCs dose important some positive attributes, compared to plastic, however, the inherent problems with wood (moisture sorption and susceptibility to mold and decay) remain. Water can penetrate into WPCs, albeit at a much lower rate and level compared to solid wood or other wood composites.

WPCs are also usually quite heavy and not as stiff as solid wood. This limits the potential use of WPCs in many structural applications and creates the potential creep or sagging problems, especially in warm environment.

WPC is touted as having environmental benefits, because is it made from residues (wood) or re-cycle material (plastic). However, virgin plastic are commonly supplemental in WPC operations to maintain tighter quality control and offset highly fluctuating recycled plastic inventories. WPC also required large amounts of energy to produce.

2.5How WPCs are made:

WPCs are commercially produced by a number of companies throughout the world. While there is considerable variation in the process employed and the products produced, there are many common elements. This section will briefly describe the component of WPCs and how they are put together.

- **Wood**
  1. **Particle geometry:**

Wood used in WPC manufacturing is in the form of dry particles with a powdery consistency, often called “wood flour.” In general, the wood waste “raw material” is in the form of sawdust and /or planer shavings.

There are two steps to produce the wood flours: size reduction and size classification (screening). In case of large pieces of wood, size may be reduced using equipment such as a hammer mill, hog or chipper. Wood from such processes is coarse and is usually ground further using an attrition mill (grinding between disks), rollers, hammer or knife mills. Wood flour can also be obtained from wood products operations such as sawmills, mill work or window and door manufactures that produce sawdust as a byproduct.

Wood flour obtained from size reduction processes or as byproduct from wood manufacturing contains various sizes of particles. These wood particles are classified using vibrating, rotating or oscillating screens. The size of wood particles is often described by the mesh of the wire cloth sieves used to make them. An important aspect of wood particles for inclusion in WPCs in their aspect ratio (the length to diameter ratio). Normally, this value will range from 1 to 5. Wood flour with a low aspect ratio is easier to process (readily metered and fed).

Higher aspect ratio can increase mechanical properties such as strength, elongation and impact energy, but high aspect ratio could decrease process ability. The equipment usedto break down and classify the wood particles will influence the aspect ratio.

2. **Wood species:**

The commonly used wood species for commercial WPCs production are pine, maple and oak. As with many wood based products, regional availability and cost are key factors in species selection.

3. **Moisture content:**

Wood flour must be dry before it is used in WPCs manufacturing. Moisture evaporates and increase gas pressure during the high temperature compounding and forming process. In addition, moisture in wood can create voids in the final product and thus adversely affect mechanical properties. Moisture is removed from the wood prior to composite formation via a Variety of drying methods, including steam tubes and rotary drums driers. Moisture is also removed during the composite processing step, minimizing its negative influence and allowing for higher product output.

- **Plastics:**

WPCs are made with thermoplastic polymers. These materials melt and flow at high temperatures and harden when cooled. To prevent excessive damage to the wood component.

Common material used is poly vinyl chloride. Recycled polymers are often used, but they must be relatively clean and homogeneous.

- **Additives:**

While the bulk of a WPC is wood flour and thermoplastic polymer, a variety of material are added in relatively small quantities. These additives are included for a variety reasons.

I. lubricant:

Lubricants are used to improve the rheology of the total formula so it will process as required. Rheology refers to how the melt behaves in processing. There can be a number of a parameter affecting where in the process the material melts (or fuses if poly vinyl chloride): apparent viscosity, apparent pressure at different process point, anti-stick attributes on the metal part of the equipment, how melt flows into different zones of the extrusion die or mold, even energy draw,etc. other terms of lubricant used interchangeably are wax, process aid, anti-stick, slip, release agent, flow modifier, etc. most of these terms describe function while wax refer to appearance of many lubricant material regardless of the actual chemistry.

The term of the internal and external lubricant are often used and depending on the perspective, can have different interpretations.

- Internal lubricants affect viscosity and flow attributes because these additives are compatible with the resin of the melt, essentially lubricating resin molecules.
- External lubricants affect anti-stick and slip attributes as these molecules will be incompatible with the melt, hence the lubricating between the melt and the metal of process equipment.

II. coupling agents:

Since there are many different types of composite, this implies there can be different chemistries of coupling agents. It also known as compatilizers, have the primary function in composite of improving the blend homogeneity of dissimilar or incompatible material. Lack of homogeneity can prevent the development of satisfactory structural properties in the end product; hence the use of these materials improves physical properties. It has also been well substantiated that there is the further advantage of reducing water absorption by the fibers in application of the end product. Reducing water absorption minimizes the fiber swelling that can distort the physical dimension of the end product.

III. stabilizers:

Stabilizers function by preventing or minimizing the deleterious chemical reactions that result in the degradation of either the composite matrix or a component of the matrix. The focus is on the stabilization of the main matrix component, polymers and fibers, subsections being antioxidants, UV stabilizers, heat stabilizers for PVC, and a few miscellaneous types considering the demands of processing and field performance.

IV. Antioxidants:

Antioxidants have two types of function: that of performing when the material is being processed, and that of performing when the end product is in use.

Most polymers upon being heated by processing start to degrade slowly, expect for PVC, which will degrade very quickly. Hence antioxidants are used for most polymers and heat stabilizer is used for PVC. Traditional antioxidant chemistries are phenolic, phosphate and thioesters. In addition to their chemistry, another way to review antioxidant through their functionality, meaning that while certain antioxidant will prevent degradation during processing, other will be more suitable to prevent degradation in field performance from deleterious effects of heat aging.

V. UV stabilizer:

The energy of UV radiation upon impacting an outdoor end product can initiate chemical reaction. Many possible reactions will utilize the presence of oxygen and water. To counter the potential of UV-initiated degradation, three strategies can be employed: blocking\screening UV energy, absorption of UV energy and finally stabilization; which is trapping radical species generated subsequent to degradation.

Blocking\screening is done with high-converge\opacity materials such as titanium dioxide, carbon black, and many pigment.UV absorption is achieved with chemistries of benzophenones and benzotriazoles.

Blocking/screening is an important concept. In WPCs the very high level of fiber can be an effective UV blocker, in that the UV radiation can only penetrate to just below the surface, so the bulk of the matrix is protected. Hence many processors achieve satisfactory product attributes without anything further than appropriate pigments used for aesthetics.

These chemistries should be used only for the prevention of polymer degradation, having no effect on preventing fade of wood fiber. Pigment systems also require separate considerations for UV protection, which are best addressed by pigment manufacturing or pigment master batch industry specialists.

VI. PVC heat stabilizer:

All the stabilizer chemistry heretofore is used to protect polymer from degrading. There is a new patent-pending technology, which purportedly claims that use will lead to less process degradation of fiber, and will result in improvements to composite physical properties, with further benefits to overall processing as well.

PVC heat stabilizers are almost always a metal ion with organic ligands. Rigid

PVC is most commonly stabilized by tin in North America and, in the rest of the world, calcium zinc is replacing lead.

VII. Filler:

The primary perspective of fillers is that they are mineral based, low cost, and added at as high a level as can be accepted by the system, so conversion costs are not inflated, and required end product attributes are not undermined, all with the intention of reducing material costs.

Filler particles can be amorphous, spherical, platelet, or fibrous. Fibrous and platelet types will have reinforcing attributes to bolster certain physical properties; the amorphous type will be the opposite and will weaken the product. Spherical types can go either way depending on particulars of the particle size distribution and the caliber of the dispersion in the matrix. Fibrous fillers can be the most difficult to process; however, if using them for effect, the proper selection of processing additives can mostly compensate. The reinforcing properties can be interpreted through a single specification for each type: if platelet shaped, consider aspect ratio (area to thickness), and if fibrous, consider dernier (ratio of length to diameter).

Other key attributes are particle size distribution, color, hardness, specific Gravity bulk density and oil absorption character. Particle size distribution can be the limiting parameter on formula content of the additive. Consider two products of the same mineral, same cost into the plant, same general properties, and same average particle size, but differing in the actual particle size distribution from which the same average particle size is derived. At either end of the distribution are the smallest particles known as `fines' and largest particle sizes known as `top-cut'. Fines have more surface area for the same weight of material than larger particles. At the same dosages of our two conjectural products, the one with more fines will cause higher melt viscosities, which generally will lower output or increase energy draw, hence dose is at the highest possible level for melt viscosity still to be acceptable for good processing, and less can be used. Alternatively, the top-cut consideration is based on the fact that weaknesses of impact resistance can always be associated with irregularities in the matrix homogeneity.

The most common mineral filler in polyolefin-based composites is talc. The platelet is purported to aid process ability as the particles align with the vector of polymer processing, and also adds reinforcing character. Carbonates are the rule in PVC, though they are amorphous. The most common carbonate is calcium carbonate; however, the dolomitic version, calcium magnesium carbonate is similar in inertness, and slightly different in crystal structure. The differentiating factor should be total net contribution of cost to end product.

VIII. Biocides:

Biocides for these composites prevent microbial species from feeding on the organic matter of the natural fiber. There are two primary types of microbial intrusion to avoid: those that occur on the surface of the composite and which are often attributed to mildew, and those that occur sub-surface and are mostly fungal. Mildew on surfaces is unsightly, while fungal rot will undermine the structural integrity of the composite by ingesting the fiber.

IX. Pigment:

Pigments are added to provide a desired color to the product. UV stabilizers can help to protect the color, but some fading and whitening will occur with most WPC's exposed to sunlight.

2.6 Manufacturing Technologies for wood plastic composite

2.6.1 Introduction:

Wood fibers and polymers are among the most important materials of our time. Both materials have advantages as well as disadvantages, especially with respect to durability, mechanical properties, swelling, thermal resistance and their potentially limited availability as a long-term resource. The compounding process offers the opportunity to combine these materials, although the compounding system must comply with special requirements in order to obtain excellent properties.

2.6.2 Compounding:

Manufacturing of WPCs can be done using a variety of processes; however, the key to making any WPC is through efficient dispersion of the wood component into the Thermoplastic matrix ('compounding'). Generally, this can be accomplished in twin-screw extruders or other melt-blending processes. Once the materials are sufficiently mixed, the composite can then be formed into the final shape using forming technologies such as extrusion or injection molding.

2.6.3 Forming:

Most WPCs are manufactured using profile extrusion, which creates long continuous elements, such as deck boards and window components. The wood-thermoplastic mixture (in pellet form) is conveyed into a hopper that feeds the extruder. As the material enters the first zone of the extruder, the heated screws and barrel melt or soften the thermoplastic. The molten material is then forced through a die to make a continuous profile of the desired shape. Molten WPC material is highly viscous, so the equipment needs to be powerful enough to force the material though the machinery and out of the die. As the material exits the extruder, it is cooled in a water spray chamber or bath to rapidly harden the thermoplastic matrix, embossed with a desired pattern, and cut to a final length. Extruders can have single screw or twin feed screws, which are counter- or co-rotating. These screws can be parallel, for mixing only, or conical, to increase pressure in the die to aid in consolidation. Tandem extruders have one component for the compounding step and one for the shaping process. While extrusion methods create lineal elements, injection molding produces three-dimensional parts and components. The unique shapes and profiles that can be created with injection molding provide the potential for diversifying from the current WPC markets. The injection molding process involves two steps. The first is to melt-blend or compound the wood-plastic mixture, and the second is to force the molten WPC into a mold under high pressure. The molten material fills the cavity in the mold and solidifies as it is cooled. Injection molding is used to manufacture a variety of parts, from small components to large objects. Injection molding is a common method of production and is especially useful for making irregularly shaped pieces.

Other types of molding processes include compression, vacuum bag, resin transfer (RTM), reaction injection (RIM) and matched die molding. These manufacturing technologies each have the ability to keep the full length of the fiber and provide high Strength composite, such as those used in automotive applications. The main disadvantages to these techniques are that they are batch processes, which re- quire longer processing times and are more costly. All of these methods could have application to WPCs; however, only limited research has addressed their use.

Figure (2.5): The WPC component

2.7 Mechanical properties of wood polymer composites:

2.7.1 Introduction

Mechanical and physical properties of wood plastic composites (WPC), such as stiffness, strength, impact resistance, and density, play an important role in deciding the suitability of these products in various applications. Recent advances in catalyst technologies for polymerization of polyolefin resins and process engineering have made WPC a material of choice for different applications.

WPCs can be labeled as true composite materials, possessing properties of both major ingredients. The key mechanical properties such as strength and stiffness of these composite materials lie between those for polymer and wood. The structure morphology plays a vital role in defining most of the functional attributes of WPC. The excellent moisture resistance of polymers compared with wood directly relates to molecular structure of plastic material used, making WPC more durable and attractive.

A wide range of applications take advantage of the functional performance that WPC offers. For example, semi-structural building products, such as decking, siding, and roofing, take advantage of improved thermal and creep performance compared with unfilled plastics. Similarly, automotive applications rely on a lower density of WPCs compared with inorganic filled thermoplastics, whereas household consumer products depend on the aesthetics.[6]

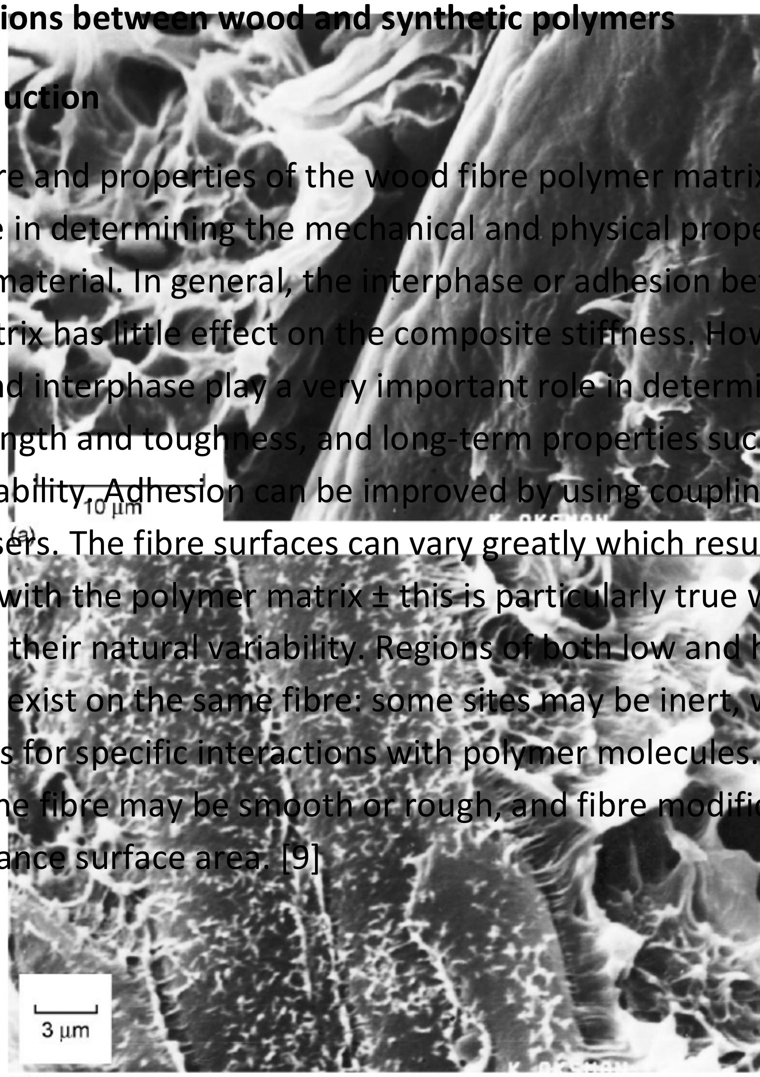
2.8 Outdoor durability of wood polymer composite

Wood plastic composite (WPC) lumber is promoted as a low-maintenance, High durability product (Clemons, 2002). However, after a decade of exterior use in the construction industry, questions have arisen regarding durability. These questions are based on documented evidence of failures in the field of WPC decking products due to such impacts as polymer degradation (Klyosov, 2005), wood decay (Morris and Cooper, 1998), and susceptibility to mold which negatively impact the aesthetic qualities of the product. The industry has responded to problems associated with first-generation products by improving WPC formulations. Manufacturers have also made great strides in making more reasonable claims and in educating consumers on the proper care and maintenance of WPC products to maintain the aesthetic quality of the surface finish. Research groups throughout the world are working toward a fundamental understanding of WPC durability that will help improve and/or identify new strategies for protecting WPCs. WPC durability will continue to be an important subject regarding the use of these products in building construction and other related applications in the field.[9]

2.9 Interactions between wood and synthetic polymers

2.9.1 Introduction

The structure and properties of the wood fibre polymer matrix interphase play a major role in determining the mechanical and physical properties of the composite material. In general, the interphase or adhesion between the fibre and the matrix has little effect on the composite stiffness. However, the adhesion and interphase play a very important role in determining properties such as strength and toughness, and long-term properties such as creep and moisture stability. Adhesion can be improved by using coupling agents or compatibilisers. The fibre surfaces can vary greatly which results in varying interaction with the polymer matrix ± this is particularly true with wood fibres (WF) due to their natural variability. Regions of both low and high surface energy may exist on the same fibre: some sites may be inert, while others provide sites for specific interactions with polymer molecules. Furthermore, the surface of the fibre may be smooth or rough, and fibre modifications may further enhance surface area. [9]



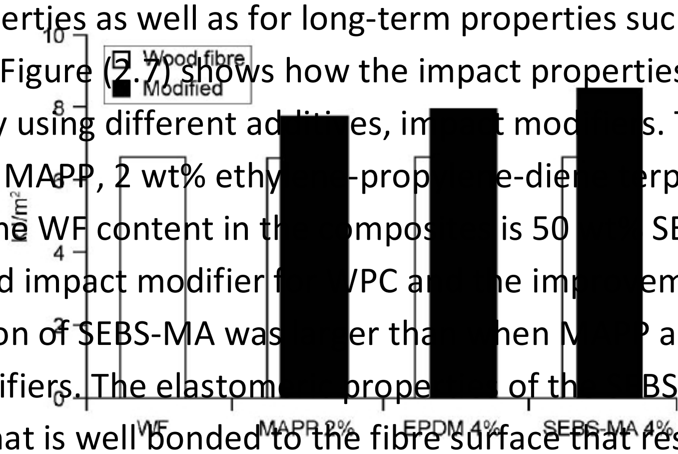
(b)

Fig (2.6) Example of (a) poor and (b) good adhesion between the wood and PE matrix (Oksman and Bengtsson, 2007).

Figure (2.6) shows scanning electron micrographs of fracture surfaces of a wood polymer composite (WPC) and the difference between poor and good interfacial adhesion in polyethylene-wood fibre (PE/WF) composite is clearly represented here. Figure (2.6) (a) shows the microstructure of the WPC when no compatibiliser was used. As can be seen, the wood fibre surface is smooth and clean and the PE matrix is rougher. Furthermore, a gap or space between the fibre and matrix can be seen, indicating poor adhesion. Figure (2.6) (b) shows the microstructure of the PE/WF composite when a compatibiliser was added. As shown in the figure, it is more difficult to discern the wood fibres since they are partially covered by the compatibiliser. Furthermore, there is no gap between the wood fibre and PE matrix, indicating good adhesion. Considerable work has been going on studying the interface, adhesion and stress transfer in wood and natural fibre composites and several groups around the world are working this area. Several special issues of the journal, Composite Interfaces (2000, 2005), have been devoted entirely to the interface, interphase and adhesion in cellulose- based composites, and more are planned in the near future.   Composite (WPC) and the difference between poor and good interfacial adhesion in polyethylene-wood fibre (PE/WF) composite is clearly represented here.

2.9.2 Interphase effects on other properties

The interphase in composites also plays an important role for toughness and impact properties as well as for long-term properties such as creep and water absorption. Figure (2.7) shows how the impact properties of WPC can be improved by using different additives, impact modifiers. The different modifiers were 1 wt% MAPP, 2 wt% ethylene-propylene-diene terpolymer (EPDM), 2 wt% SEBS-MA. The WF content in the composites is 50 wt%. SEBS-MA was shown to act as a good impact modifier for WPC and the improvement in impact strength upon addition of SEBS-MA was higher than when MAPP and EPDM were used as impact modifiers. The elastomeric properties of the SEBS provide a flexible interlayer that is well bonded to the fibre surface that results in the improved impact properties. Theoretical analysis of a flexible interlayer suggest that assuming there is good adhesion, the flexibility (or compliance) and the thickness of the interlayer are both important factors in determining impact improvement and stress transfer efficiency and composite properties can be tailored using those two parameters (Oksman and Clemons, 1998). Sain and Kokta (1994) studied the effect of epoxy-coated WF on the toughening of WPC. The crosslinking of epoxy resin resulted in enhanced energy absorption properties of the polypropylene composites.[9]



Source : wood polymer composite (edited by KristiinaOKsmanNiska and MohiniSain)

Fig (2.7): The effect of different modifiers on the un-notched Charpy impact strength of WPC

2.10 Characteristics of raw materials

This section will discuss the characteristics of wood and plastics that make them susceptible to degradation, and the degradation mechanisms of each component. A discussion of structure and composition of wood and polymers in WPCs can be found above. [9]

- **Wood**

i- Weathering

Wood is very susceptible to the effects of weathering including the primary impacts of ultraviolet (UV) light, oxidation, rain, and combinations of light, oxidation, and rain. Wood is hygroscopic, readily absorbing moisture due to the prevalence of hydroxyl groups. All wood components are also susceptible to degradation by UV radiation. However, lignin is primarily responsible for UV absorption. Of the total amount of UV light absorbed by wood, lignin absorbs 80±95% (Fengel and Wegener, 1983). Chromophoric functional groups present in lignin can include phenolic, hydroxyl groups, double bonds, and carbonyl groups. In addition, lignin can form free radicals as intermediates. Photo-degradation of wood begins with an attack on the lignin-rich middle lamella. Longer exposure leads to a degradation of secondary walls (Fengel and Wegener, 1983). UV light degrades lignin into water-soluble compounds that are washed from the wood with rain, leaving a cellulose-rich surface with a fibrous appearance.

The effects of UV degradation are largely surface phenomena. UV light cannot penetrate deeper than 75 "m into wood. However, studies investigating depth of degradation show that degradation occurs deeper than this. The result is a proposed mechanism where wood components at the surface initially absorb

UV light, and then an energy transfer process from molecule to molecule dissipates excess energy to create new free radicals. In this way, free radicals migrate deeper into wood and cause discoloration reactions (Hon and Minemura, 2001). After long exposure times, lignin content through the thickness of wood changes gradually even beyond the discolored surface layer, with less lignin at the surface and more in the center portion (Hon and Minemura, 2001).

Photo degradation leads to changes in wood's appearance such as discoloration, roughening and checking of surfaces, and destruction of mechanical and physical properties. All wood species eventually will fade from a brown, red, or yellow color to a light grey during weathering. Wood weathering is visually apparent in untreated wood and in WPCs that do not contain a colorant. [9]

ii- Biological attack

The natural origin of wood predisposes it to degradation by a variety of biological deterioration agents. Wood chemical components provide a food source for a variety of biological organisms including insects, fungi, bacteria, and marine borers.

Brown-, white-, and soft-rot fungi (see below) all contribute to the decay of wood. The conditions essential for fungal growth in wood are food, sufficient oxygen, suitable temperature, and adequate moisture. Wood itself provides the necessary food, and oxygen is readily available in the environment. A wood moisture content of approximately 20% is required for decay. Below this level degradation due to fungal attack will not occur, and fungi that may have already begun to grow will cease growing (Naghipour, 1996). As a general rule, if wood is kept dry, i.e. moisture content below 20% then fungi typically will not attack wood. However, in unprotected outdoor or marine exposures, wood can be exposed to high levels of moisture that provide the necessary conditions for

iii- biological attack

Insects that attack wood include termites, wood destroying beetles, carpenter ants, and carpenter bees. Marine borers that attack wood include shipworms (teredineds) and piddocks (pholads).

- **Polymers**

Polymers degrade by chemical, mechanical and / or thermal modes. The major polymer matrices used in WPCs include high- density polyethylene (HDPE), low-density polyethylene (LDPE), polypropylene (PP), and polyvinyl chloride (PVC). More recent work describes the use of nylon as a polymer matrix for WPCs (Chen and Gardner, 2008). Polymer additives used in WPC processing include lubricants, colorants, light stabilizers, anti- oxidants and coupling agents. Specific additives or combinations of additives can potentially contribute to degradation. For the most part, polymers and polymer additives are much less susceptible to biological attack than wood; but polymers, like wood, are susceptible to the weathering effects of UV light and oxidation.

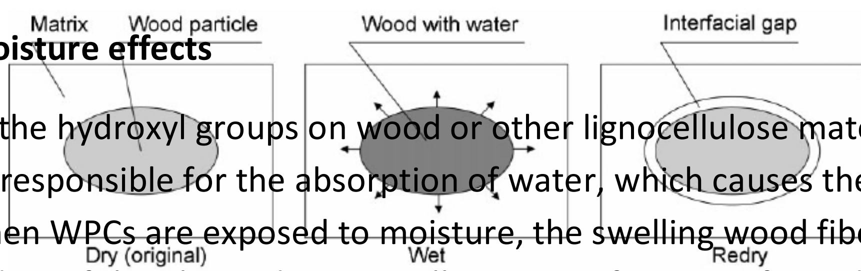
PE and PP are linear molecules consisting of carbon and hydrogen. The energies of photons in the UV region (290±400 nm) are significantly higher than bond energies typically found in PE and However, the excitation of single bonds requires an amount of energy that is also significantly higher than the bond energy (Gugumus, 1995). Therefore, photo- degradation of polyolefin is caused mainly by the presence of chromospheres, functional groups that readily absorb UV light, introduced during polymer manufacturing, processing, or storage. They include catalyst residues, hydro- peroxide groups, carbonyl groups, and double bonds (Gugumus, 1995). Photo degradation of the chromospheres yields free radicals, which then give rise to compounds containing hydroxyl groups, carbonyl groups, and vinyl groups (Wypych, 1995). As semi crystalline polymers, the packing of the crystalline phase is much tighter than that of the amorphous phase. Oxygen diffusion into crystalline segments is restricted (Wypych, 1995). Comparing PE and PP, the degree of branching determines the oxidation rate; more branching results in more labile hydrogen atoms attached to the tertiary carbon atoms.

PVC contains C±Cl, C±C, and C±H bonds. None of these absorb UV radiation. PVC is degraded by residual solvents, unsaturation's, irregularities in polymer structure, and thermal history. Photo degradation proceeds via a free radical pathway and leads to dehydrochlorination, chain scission, and cross- linking. Incorporation of a plasticizer increases the rate of oxygen diffusion (Wypych, 1995).

Indications of photo degradation include oxidation of the polymer, changes in crystallinity, and structural changes such as crosslinking and chain scission. Photo degradation is a surface phenomenon and can lead to the formation of surface cracks, embrittlement, and loss of strength and modulus of elasticity (MOE). PP (e.g. C±C and C±H bonds).

2.8.3 Changes in composite properties with exposure

Environmental, biological, chemical, mechanical, photo(light)-induced, and/or thermal modes of degradation all contribute to the degradation of WPCs. Outdoor durability, by its very nature, exposes WPCs to degradation modes that can act synergistically.



- **Moisture effects**

In WPCs, the hydroxyl groups on wood or other lignocellulose materials are primarily responsible for the absorption of water, which causes the wood to swell. When WPCs are exposed to moisture, the swelling wood fiber can cause local yielding of the plastic due to swelling stress, fracture of wood particles due to restrained swelling, and interfacial breakdown (Joseph et al., 1995). Figure (2.8) illustrates this mechanism. Initially, there is adhesion between the wood particle and matrix in a dry WPC. As the wood particle absorbs moisture, it swells. This creates stress in the matrix, leading to the formation of micro cracks. It also creates stress in the wood particle, causing damage. After drying the composite, there is no longer adhesion at the matrix and wood particle interface. Cracks formed in the plastic and the interfacial gap contributes to penetration of water into the composite at a later exposure. [9]

Source : wood polymer composite (edited by KristiinaOKsmanNiska and MohiniSain)

Fig (2.8) Schematic of moisture damage mechanism in WPCs.

Damage that occurs during moisture exposure degrades mechanical properties. Micro cracks in the matrix and damage to wood particles cause a loss in MOE and strength. Interfacial damage is primarily responsible for a loss in composite strength. The effects can be dramatic. For example, after soaking 40% wood flour filled PP composites in a water bath for 2000 hours; the water absorption of the composites was 9%. This corresponded with a 39% decrease in flexural MOE and a 22% decrease in flexural strength (Stark, 2001).

- **Thermal changes**

Thermal response of polymers can impact mechanical properties, especially creep, and physical properties, i.e. coefficient of thermal expansion which can impact in-service properties of WPCs. Depending on the particular climatic exposure, WPCs used in decking applications can experience temperatures ranging from À30 ^{o}C to 50 ^{o}C. The primary thermal changes impacting WPC properties include thermal expansion, mechanical creep, and thermal-oxidative degradation. Increased temperatures can also act synergistically with other chemical degradation mechanisms to increase reaction rates.

- **Mechanical creep**

Thermoplastic materials such as WPCs will experience changes in mechanical (stiffness) properties as a function of increased temperature. Materials under a mechanical load that might perform adequately at normal service temperatures may experience creep under loads for extended periods of time and at higher temperatures (Brandt and Fridley, 2003).

- **Weathering**

WPCs exposed to weathering may experience color change, which affects their aesthetic appeal, as well as mechanical property loss, which limits their performance. Changes in mechanical properties after weathering can be due to changes such as composite surface oxidation, matrix crystallinity changes, and interfacial degradation. Although photo degradation of both polymers and wood has been extensively examined, the understanding of WPC weathering continues to evolve as several research groups work on characterizing and understanding changes that occur when WPCs weather.

- **Biological attack**

Insects and marine borers

Insect attack of wood can include attack by termites, beetles, and ants. There is little information in the area of insect attack on WPCs, but one on-going study reported termite activity after 3 years in-ground exposure in Mississippi (Ibach and Clemons, 2004). After the first and second year of in-ground exposure, there was no reported termite attack on 50% wood flour/HDPE composites. After the third year, nibbles of up to 3% cross-section were reported.

Marine borer attack includes attack of wood by shipworms and crustaceans. Although marine borers present a problem to untreated wood, they are not considered a threat to WPCs based on limited field studies. Pendleton and Hoffard (2000) exposed HDPE composites containing 50% or 70% wood flour to a natural marine environment in Pearl Harbor, Hawaii. After 1, 2, and 3 years the WPC specimens showed no visible marine borer attack (Pendleton and Hoffard, 2000).

2.11Market:-

WPCs are widely used in the U.S and in north American WPC market reached almost $1 billion in sales. This is increase of 200% between 2001 and 2006, and it's expected that 20% annual growth will take place within the next 5 to 6 years.

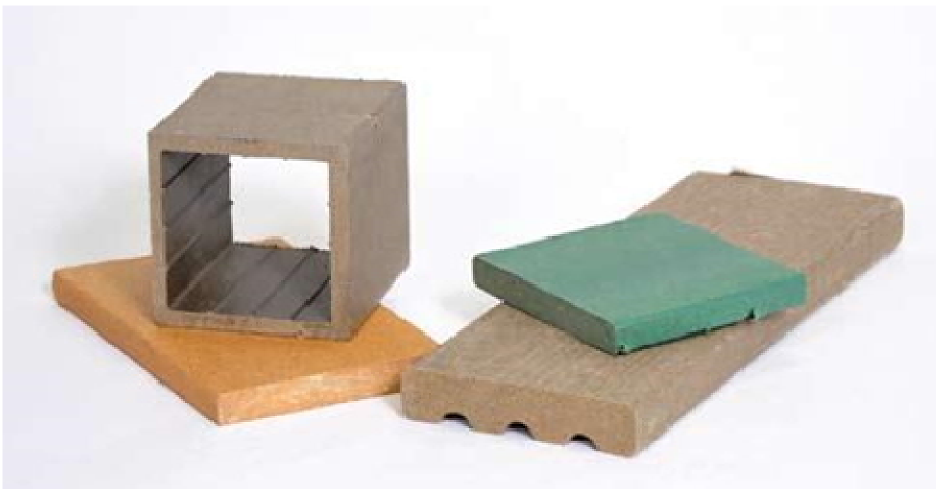


Figure (2.9): WPCs can be produced in almost any color and shape. Hollow decking boardsCan reduce material usage.

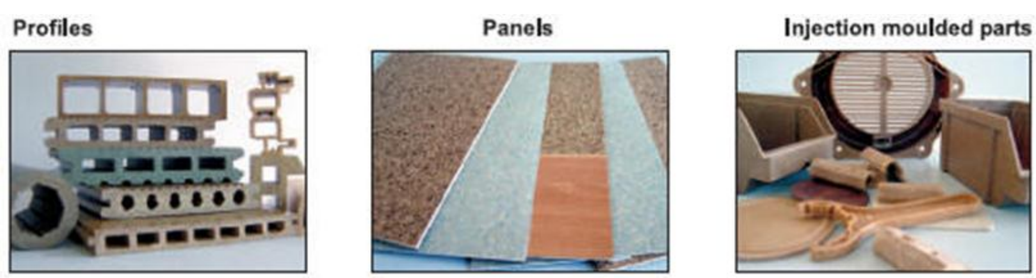


Figure (2.10): Types of WPC end product

Chapter Three

material and method

3.1 Material:

i- chemical

plastic poly vinyl chloride PVC

wood (mah)

ii- e

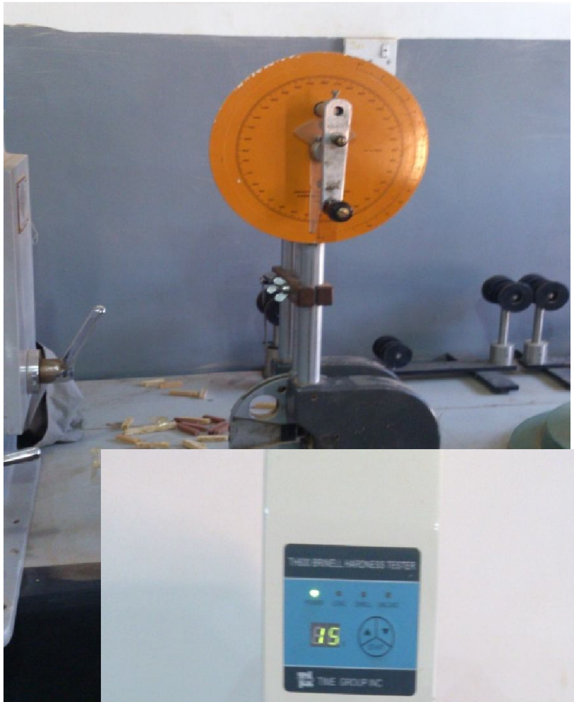


Figure (3

Figure (3.2): Ha

Figure (3.3): Oven

3.2 Methodology:

Firstly samples were taken from Moawia's factory for wood furniture in Khartoum North which made by compounding the PVC with wood (sugar cane) and some additives then produce a sheet by using extrusion machine.

Secondly take WPCs samples and other wood types for testing to confirm the WPCs is best than wood itself; and also compare this different types of wood to show the better one using in compounding with PVC where available in Sudan. All this tests made in Sudan university of science and technology.

3.3 The experimental tests:

I. Density

Calculate the density of samples that defined as the mass per unit volume of material.

Density = the weight of dry sample / volume

II. Absorption test

By using samples in triangles shape weighed with boot in air; put them in water for 24 hours and weight again; then take these samples full of water and put in oven 110-115 o for one hour to dry and weight again; finally by using law to found the percentage of absorption for each samples.

Samples shape rectangle (1.5*15*52.6) cm

% = (w3-w2/w2-w1) * 100

Where:

W_3 the weight of sample full of water

W_2 the weight of dry samples

W_1 the weight of empty boot

III. Hardness test

By using BERINLL HARDNESS NUMBER (BHN) put the samples under the indentor (metal boll) on the surface then press it into the samples making shore that is parallel to the surface; then measured the penetration by using lenses to reading the number of dimension of indentor penetration in it; finally using the law below to calculate the BHN.

Samples shape are rectangle (11*11*152) mm

BHN = 0.102 [2*F(N)/pi*D(D-(D^2-d^2))]

Where:

F(N) = 20Kg * 9.81= 196.2 N

D the diameter of metal boll

d the diameter of penetration

IV. Impact test

By using SHARP MT220 put the samples parallel to the surface after moving the leg of machine to app then let it move down to impact with sample and crush into two half's.

Samples shape rectangle (8*8*75) mm

$P = mgl [\sin(\Theta_1 - 90) + \cos \Theta_2]$

Where:

P the energy absorbed

Θ_1 the angle before impact

Θ_2 the angle after impact

M = 2Kg

L =0 .39 m

G =9.8 m/s^2

V. Burning test

By using samples for each type of material, put it on fire and let them until burn completely then calculate the time which take them.

Figure(3.5): WPCs samples after burning

Figure (3.6): other type of wood samples after burring

Chapter four

Results and discussion

The result of the physical tests are summarized below:

Table (4.1): Density test

Samples	Density g/cm^3	Density g/cm^3	Density g/cm^3	Average
WPC	0.68	0.68	0.68	0.68
Musky	0.625	0.625	0.625	0.625
Sugar cane	0.662	0.662	0.662	0.662
Mahogany	0.777	0.777	0.777	0.777
Sunut	0.859	0.859	0.859	0.859

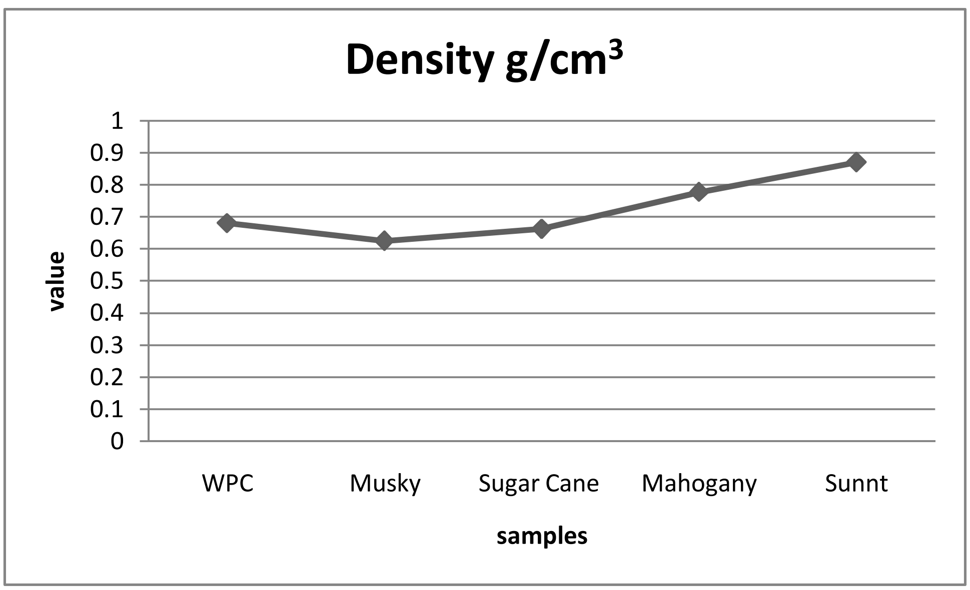


Figure (4.1): Density of samples

Table (4.1) and figure (4.1) shows the density of WPCs are approximately equal to other samples of wood that's mean the weight of composite is light, good in shaping and work.

Table (4.2): Absorption test

Samples	Absorption %	Absorption %	Average
WPC	0.034	0.034	0.034
Musky	0.06	0.06	0.06
Sugar cane	0.15	0.15	0.15
Mahogany	0.251	0.251	0.251
Sunut	0.104	0.104	0.104

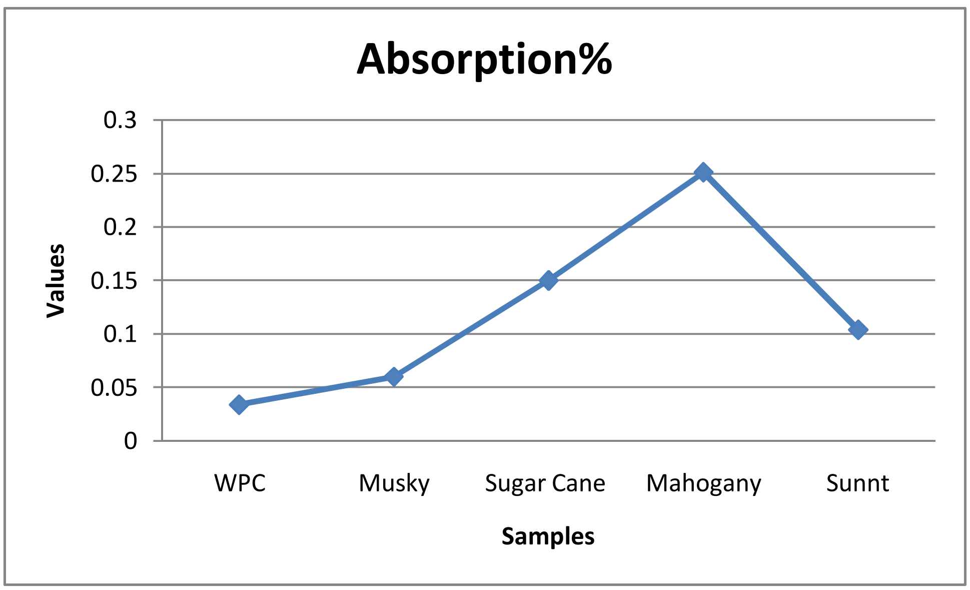


Figure (4.2): Absorption of samples

Table (4.2) and figure (4.2) shows that the percentage of WPCs moisture absorption are very good that's mean the composites are resistance to water. Also musky has low percentage of water absorption than other.

Table (4.3): Hardness test

Samples	Hardness	Hardness	Hardness	Hardness	Hardness	Average
WPC	10	8.9	10	8.1	9.1	0.21
Musky	8.0	8.6	8.5	8.0	7.1	0.31
Sugar cane	5.9	6.8	7.0	7.0	7.1	0.48
Mahogany	6.5	6.5	6.5	6.5	6.6	0.53
Sunut	4.5	4.4	4.4	4.5	4.5	1.19

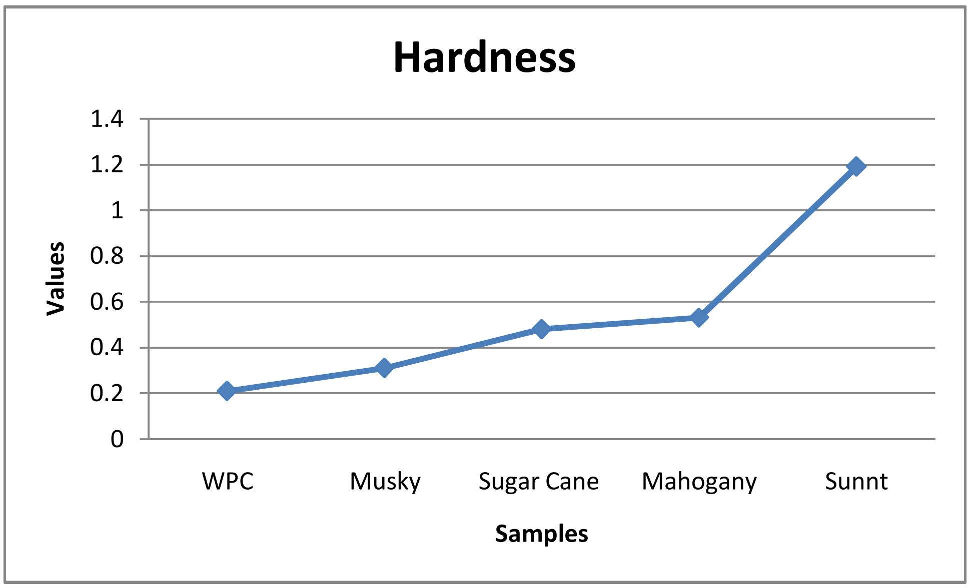


Figure (4.3): Hardness of samples

Table (4.3) and figure (4.3) shows the hardness of WPCs arelow which means are flexible so we can used in different forms**.** Also musky is low reading and sunut is highest one.

Table (4.4): Impact test

Samples	Impact	Impact	Impact	Impact	Average
WPC	1.24	1.24	1.24	1.24	1.24
Musky	3.56	4.04	3.22	3.56	3.52
Sugar cane	1.86	1.86	1.86	1.86	1.86
Mahogany	2.66	2.88	3.44	3.44	2.99
Sunut	3.22	4.53	2.99	2.99	3.58

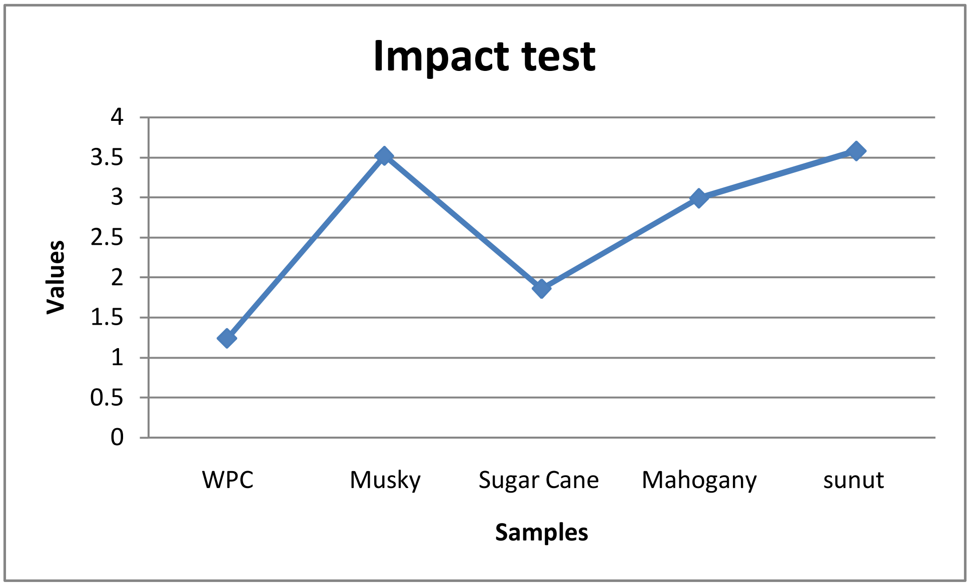


Figure (4.4):The impact test of samples

Table (4.4) and figure (4.4) shows that impact of WPCs are low due to the type of wood(sugar cane) used in composite, so we can improve this by using other type of wood because it is responsible of it in the composite**.**The musky was found to be the highest reading so we can replace it with sugar cane which is lowest reading.

Table (4.5): Burning test

Samples	Time min	Time min	Time min	Average
WPC	Less than 1	1	1	0.333
Musky	7	8	8	7.666
Sugar cane	8	10	10	9.333
Mahogany	8	9	13	10.00
Sunut	6	7	8	7.000

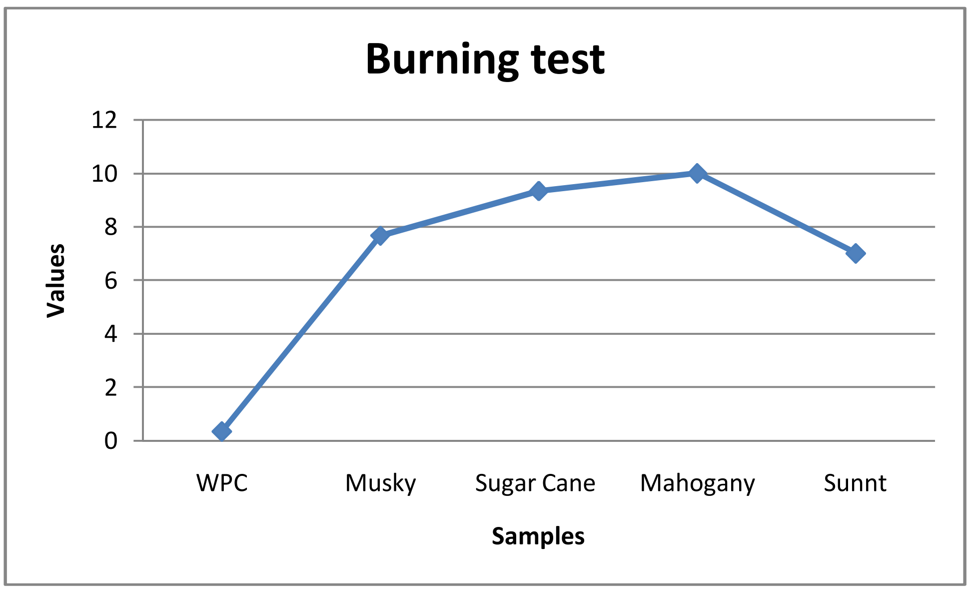


Table (4.5) show the WPCs are not burning that's mean its excellent resistance to fire and safe for use. Also Sunnt is low resistance than sugar cane so we can replace it.

Chapter five

Conclusion and recommendation

Conclusion:-

- WPCs as a shape of sheets its very good, the surface is soft, flexible and weight is light.
- The mechanical properties tests approve its excellent in water absorption which it's an important point that making for it.
- Also in other mechanical test the result are light in weight and flexible so can used for making furniture like beds, tables and cupboard; sheets for flooring.
- But in impact test the result is weak which can break easy that's refer to the type of wood alone also weak in the same test so to improve this we can choose another type of wood.
- About the fire test the WPCs have excellent resistance than the wood due to the type of plastic used in the compound which known as a fire retardant.
- The other type of wood in Sudan where select some of it the mechanical properties also good but the musky have properties better than the sugar cane that used in compound so we can change it especially to improve the impact of the product.

Recommendation:-

- Make WPCs using musky as a wood and then study it to the mechanical properties.
- Using the waste of wood in the compounding to reduce the cost.
- To encourage more studies about this section to improve the mixture between the plastic, wood and having low cost.
- To re-search about the biological attack test.
- Establish more factories to increase the product of WPCs.

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