EFFECT OF FIBER COMPOSITION ON MECHANICAL AND PHYSICAL PROPERTIES OF HIGH LOADING WOOD FIBER COMPOSITES

By

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LIST OF ABBREVIATIONS

ABS	Acrylonitrile butadiene styrene
APCP	Advanced Polymer and Composite Programme
ASTM	American Society for Testing and Materials
CLTE	Coefficient of linear thermal expansion
DMA	Dynamic mechanical analysis
EFB	Empty fruit bunch
FAO	The United Nation Food and Agriculture Organisation
FRIM	Forest Research Institute of Malaysia
HDPE	High density polyethylene
MAPE	Maleic anhydride grafted polyethylene
MAPP	Maleic anhydride grafted polypropylene
MOSTI	Ministry of Science, Technology and Innovation of Malaysia
PE	Polyethylene
PP	Polypropylene
PVC	Polyvinyl Chloride
RH	Rice husk
RH-PP	Rice husk polypropylene composite
RH-PP	Rice husk polypropylene composite
SD	Sawdust
SD-PP	Sawdust polypropylene composite
SEM	Scanning electron microscopic
UPCV	Un-plasticised Polyvinyl Chloride
US	United State

USA	United State of America
UTM	Universal testing machine
UV	Ultra violet
WPC	Wood polymer composite

LIST OF SYMBOLS

%	Percent
% RH	Percent relative humidity
g	Gram
g/10 minute	Gram per ten minute
g/cm^3	Gram per centimeter cube
J	Joule
kg	Kilogram
mm	Millimetre
mN	Milinewton
MPa	Mega Pascal
N	Newton
^oC	Degree Celsius
$SG_{Apparent}$	Apparent specific gravity
T_g	Glass transition temperature
W	Increased in weight
$W A_{H2O}$	Weight of sample in water
$W A_{sample}$	Weight of sample
Wo	Conditioned weight in air
Wt	Wet weight
Wt. %	Weight percentage

KESAN KOMPOSISI GENTIAN KE ATAS SIFAT-SIFAT MEKANIKAL DAN FIZIKAL KOMPOSIT GENTIAN KAYU BERMUATAN TINGGI

ABSTRAK

Sifat mekanikal komposit polimer kayu yang terdiri daripada polipropelina (PP) dan campuran pengisi kayu (SD) sebahagian besar dari spesis meranti dan juga pengisi serbuk sekam padi (RH) adalah dikaji. Tiga peratusan berat pengisi berbeza iaitu pada kadar 50 %, 60 % dan juga 70 % digunakan dalam proses gaulan dan penyemperitan menggunakan mesin penyemprit skru berkembar. Modulus fleksural dan modulus tegangan mengalami peningkatan manakala kekuatan tegangan, kekuatan fleksural, pemanjangan takat putus dan juga kekuatan hentaman mengalami penurunan apabila nisbah jumlah pengisi bertambah. Kemampuan serapan air meningkat dengan ketara apabila kadar pertambahan pengisi bertambah terutamanya komposit dengan 70 % berat pengisi. Komposit dengan kandungan pengisi sebanyak 50 % berat menghasilkan keputusan mekanikal dan fizikal yang optima, ianya juga digunakan dalam kajian seterusnya iaitu mengkaji kesan pengunaan agen penserasi. Kajian penambahbaikan pelekatan antaramuka di antara pengisi dan matrik PP menggunakan agen penserasi “maleated” dicangkuk PP (MAPP). Agen penserasi MAPP digunakan pada kadar 1 %, 2 % dan 3 % berat. Penambahan agen penserasi MAPP menghasilkan peningkatan kekuatan tegangan, modulus tegangan dan sifat fleksural. Pada kebanyakan masa, meningkatan ketara dapat dilihat apabila 1 % berat MAPP digunakan, penambahan % berat MAPP seterusnya tidak menghasilkan peningkatan yang bermakna kepada pengujian yang dibuat. Komposit SD-PP pada setiap kali pengujian menghasilkan sifat mekanikal dan fizikal lebih baik berbanding komposit RH-PP, kadar nisbah aspek yang lebih baik yang ada pada pengisi SD

adalah penyebab utama. Komposit SD-PP saterusnya digunakan untuk mengkaji kesan pendedahan sampel kepada situasi persekitaran yang mencabar. Sifat kekuatan tegangan dan fleksural komposit mengalami penurunan setelah didedahkan pada persekitaran yang mencabar. Sifat ketengan dan fleksural komposit SD-PP yang terdedah kepada sinaran Xenon adalah paling terjejas berbanding pendedahan situasi persekitaran yang mencabar lain. Komposit SD-PP tanpa MAPP mengalami penurunan sifat modulus ketegangan sehingga 46 % dan kejatuhan sifat mekanikal ini di sebabkan oleh pengoksidaan foto dan pemutusan rantaian molekul polimer. Degredasi sampel selapas 1000 jam pendedahan terhadap sinaran Xenon juga telah dibuktikan dengan analisis perubahan warna yang mana didapati kesemua sampel mengalami perubahan warna yang amat ketara.

EFFECT OF FIBER COMPOSITION ON MECHANICAL AND PHYSICAL PROPERTIES OF HIGH LOADING WOOD FIBER COMPOSITES

ABSTRACT

The mechanical properties of wood polymer composites (WPC) consisting of polypropylene (PP) and mixed sawdust (SD) of meranti *shorea spp*. dominant and rice husk (RH) filler have been studied. Three different fillers loading of 50 wt. %, 60 wt. % and 70 wt. % were used and the process of compounding and extrusion was carried out using a twin screw extruder. Increase in flexural modulus and tensile modulus are observed while tensile strength, elongation at break, flexural strength and Izod impact strength decrease with increasing filler loading. Water absorption capability increased significantly with the increased of filler loading especially composite with 70 wt. % filler loading. Composites with 50 wt. % of filler found to have an optimum mechanical and physical property, thus being used for further study on the effect of coupling agent. The interfacial bonding between wood filler and PP matrix were studied using maleic anhydride grafted polypropylene (MAPP). Three different loading of MAPP with 1 wt. %, 2 wt. % and 3 wt. % were used in this study. Addition of the MAPP shows some improvement especially tensile strength, tensile modulus and flexural properties. Most of the time, an improvements were observed at 1 wt. % of MAPP, further increment of the MAPP did not show any significant impact on the property tested. SD-PP composites consistently produce an excellence mechanical and physical property to compare with RH-PP composite, better aspect ratio value of SD filler is the main reason for the excellence property. SD-PP composites were used for further study on the impact of difference type of

specimens conditioning. Tensile and flexural properties decreased with the exposure to difference extreme conditions. The tensile and flexural properties of the SD-PP composite exposed to xenon-arc light affected most to compare with other exposure. SD-PP composite (without MAPP) experience drop in tensile modulus about 46 % and the drop of mechanical properties is due to the photo-oxidation and chain scission of the polymer molecule. The degradation of specimens after 1000 hours exposure Xenon-arc light was also proven by colour change analysis where it is found that all samples lost most of it original colour.

CHAPTER 1 - INTRODUCTION

1.1. Background of research study

Wood Polymer Composite (WPC) refers to composites that contain wood/natural filler and plastic resins (matrix). The fillers may be sourced from wood such as softwood and hardwood (Mirbagheri *et al.*, 2008 and Aranguren *et al.,* 1998) or any non-wood sources such as cotton, flax, hemp, jute, kenaf, rice husk, etc. The fillers used for producing the composites may be in the form of flour, short fibres, chips and particles.

The use of natural filler materials as a filler and reinforcement in thermoplastics such as polypropylene (PP), polyvinyl chloride (PVC) and polyethylene (PE) are getting popular (Adhikary *et al.*, 2008). Incorporation of organic fillers in thermoplastics is not new but had started as early as in the 60's. This method became popular in the late 90's due to increasing plastics cost and the trend on using renewable materials. According to H'ng *et al*. (2008), growing interest of using WPC in construction and industrial product is due to its renewability, less abrasive to processing equipment, environmental friendly, low maintenance and similarity to wood features. The use of waste natural fillers as filler had resulted in the promotion of WPC as environmental friendly products.

The objective of this study is to explore the effect of high filler loadings and coupling agent on the physical and mechanical properties of the wood polymer composites using locally resource natural fillers. The ultimate aim of this study is to provide competitive alternative material to natural wood which is diminishing in supply and is becoming more expensive.

Although many research work have been conducted on the properties of wood polymer composite (Tajvidi and Takemura, 2010, Li *et al.*, 2010 and Gu and Kokta, 2010), little has been reported on high filler loading using the profile extrusion process. One of the main reasons that not much work has been done on WPC with more than 50% filler contents is the availability of suitable processing equipment. However, a number of researchers have studied extruded WPCs with filler content of more than 50% such as Pathapulakkal *et al.* (2005) who used extruded sample to study the effect of coupling agent on the composite of HDPE filled with 65 % rice husk. Soury *et al.* (2011) used extruded WPC with up to 70% filler content to study the relationship between surface quality and water absorption.

According to Sercer *et al.* (2009), extrusion is the main method in WPC production and commonly used by WPC manufacturer all over the world and the products are widely used in verity of area such as decking, railing, shingles, window frame and door profiles.

Methods that used by researchers in preparing the test samples for the evaluation of the properties of the formulated materials included extrusion, compression and injection molding. Compression technique is one of the most popular methods used to prepare the samples for testing. It is considered to be one of the most practical methods for sample preparation and is being used by many researchers such as Bin and Jinmei (2004) and Gu and Kokta (2010).

Injection molding technique is also a popular method for sample preparation, Bengtsson and Oksman (2006), Yang *et al.* (2006) and Zabihzadeh *et al.* (2010) used this technique to prepare their test samples. According to Behravesh *et al.* (2002), the properties of the material obtained from the injection molded samples is more superior as the high pressure at the holding step and resulted in highly compacted products.

Shakouri *et al.* (2009) used test samples from extruded profiles in his study on effect of die pressure on mechanical properties of wood-plastic composites in extrusion process. He reported that in the extrusion process, the system cannot be easily controlled to a very high pressure, thus will limit the chances to superior test samples.

1.2. Problem statement

The main disadvantage of wood polymer composite (WPC) seems to be the poor dispersion of fillers and incompatibility between hydrophilic natural fillers and hydrophobic thermoplastic matrix (Keener *et al.*, 2004). The strength of the composites very much depends on the dispersion and compatibility between materials.

Compatibilizers or coupling agents are often used to improve interfacial bonding of the two different phases. The most popular coupling agent that is being used by many researchers is maleic anhydride grafted polyolefin such as maleic anhydride grafted polyethylene (MAPE) and maleic anhydride grafted polypropylene (MAPP)

(Lai *et al.,* 2003). There are some studies on the use of other coupling agents such as silane (Espert *et al.,* 2004) and isocyanides (Raj *et al.,* 1989). It had been clearly demonstrate that, the incorporation of coupling agents into the composites resulted in a significant improvement to the mechanical properties of the composites.

As the outdoor applications of WPC become more widespread, the durability of its products against weathering, particularly the ultra-violet (UV) light becomes of concern. UV exposure can cause changes in the surface chemistry of the composite, also known as photo-degradation, which may lead to discoloration making the products aesthetically unappealing (Stark and Matuana, 2003 and Stark *et al.,* 2001). Scientists have begun to investigate the UV durability of WPC. Work with wood filler reinforced polyolefin composites has focused mainly on changes in appearance and mechanical properties (Stark and Matuana, 2003).

Another main concern is the hydrophilic nature of natural filler, which results in an incompatibility with hydrophobic polymeric matrices leading to poor mechanical properties. Further, in moist environment, due to this hydro-philicity, swelling by water uptake can lead to micro-cracking of the composite and degradation of mechanical properties (Peijs *et al.* 1998). For this to be predictable, an understanding is required of the relationship between water absorption with mechanical properties.

1.3. Objectives

In this study, the natural fillers and polypropylene were compounded using a twin screw compounder. The compounded materials were extruded into profiles. Test specimens were cut from extruded profiles. Three (3) main objectives of this study are listed below:

i. To characterize the mechanical and physical properties of high-filled wood polymer composite profiles using rice husk (RH) and sawdust (SD):
   - To compound and extrude the profiles 50, 60 and 70 wt. % of filler.
   - To study the effect of filler on the mechanical and physical properties of the extruded profiles.

ii. To investigate the effectiveness of incorporating coupling agent into the selected composite compounds:
   - To use coupling agent from maleic anhydride grafted polypropylene (MAPP) with amounts of MAPP used are set at 1, 2 and 3 wt. %.
   - To investigate the effects of different percentage of MAPP relating to the mechanical and physical properties of the composites.

iii. To investigate the effects of three different types of environmental conditioning exposure on the mechanical properties of the composites:
   - The types of exposure is as below:
     i. Temperature cycle
     ii. Immersion in distilled water at room temperature for 24 hours

iii. Exposure to accelerated weathering using Xenon-arc light for 1000 hours.

- Evaluation of the mechanical properties of the composites after the exposures.

CHAPTER 2 – LITERATURE REVIEW

2.1. Introduction to composite

Composites are comprised of combinations of two or more different materials with different composition of form. The constituents retain their identities in a composite and do not dissolve or merge, but act together (The Aviation History Online Museum).

A composite may have a ceramic, metallic or polymeric (thermoset or thermoplastic) matrix. The fillers can also be ceramic, metallic or polymeric. However, a more common classification relates to whether they are synthetic (e.g. glass fibre, carbon fibre, kevlar fibre) or natural (wood fibre, hemp fibre, flax fibre, jute fibre, etc). Therefore, the number and variety of composites available are very large (Beg, 2007).

Natural fillers have been used as reinforcement in composite materials since the beginning of our civilisation, when grass and straw or animal hairs were used to reinforce mud brick, also known as adobe (Cook, 1980). In ancient Egypt, Pharaoh Mummies were wrapped in linen cloth impregnated with Dead Sea salt, natural resins and honey in order to protect and reinforced them. This was, most likely, the first known man-made material composite in human history.

2.2. Introduction to wood polymer composites (WPC)

Wood polymer composites (WPC) are a new type of materials that are generating a lot of interest in wide variety of areas. The term WPC refers to any type of composites that contain wood (of any form) and incorporated into either thermoset or thermoplastics polymer (Daniel *et al.,* 2005).

WPC using thermosets as a matrix dated to early 1900s. An early commercial composite marketed under the trade name Bakelite was composed of phenol-formaldehyde and wood flour. Its first commercial use was reportedly as a gearshift knob for Rolls Royce in 1916 (Gordon, 1988).

The birth of the WPC industry involves the interfacing of two industries that historically knew little about each other and had very different knowledge bases, expertise and perspectives. The forest product industry has great experience and resource in the building products market and its production methods centre around the typical wood process: sawing, veneering, chipping, flaking and gluing. The plastics industry has knowledge of plastics processing that centre around extrusion, compression-moulding and injection-moulding technologies. Not surprisingly, some of the earliest companies to produce WPC's were window manufacturers that had experience with both wood and plastics (Daniel *et al.,* 2005).

The wood fillers can be from sawdust or scrap wood products. This mean that no additional wood resources are used in WPCs. Waste products that currently cost money for disposal are now valuable resources. Recycling is now viewed as both profitable and ethical. The plastics can be from recycled sources such as plastics bags and recycled battery case materials. Virgin plastics materials are often used for product with demanding applications.

The WPC are used mainly in building and construction, motor vehicles, interior design, sports and leisure. The use of WPC is a norm in North America and it is getting popular in Europe (Mali *et al.*, 2003). The use of WPC in Malaysia is relatively low but Malaysia has a lot of natural resources with the possibility to be used in producing WPC. Palm oil fibre (empty fruit bunch and oil palm frond), rice husk, kenaf, rice straw and sawdust are the most widely used natural fillers in WPC industry in Malaysia.

Natural fillers have a good potential for replacing of conventional fillers such as talc, calcium carbonate, carbon and glass fibres. With the proportion varies from 10 % to 80 % between the two main materials, WPC have the advantages of having the characteristics for both, natural fillers and polymer. The main advantage of using natural fillers in composites products are that they are from renewable resources, lighter and are less expensive.

Extrusion is the most common processing method for WPCs and manufacturers use a variety of extruder types (such as single screw, twin screw with co-rotating or twin screw with counter-rotating) and processing strategies (Mapleston, 2001). Certain manufacturers run compounded pellets through single-screw extruder to form the final shape. Others compound and extrude final profiles in a single-step process using twin-screw extruders.

According to Daniel *et al.*, (2005), there are few companies which are specializing in producing WPC compound or pellets using wood and other natural fillers mixed with thermoplastics. These compounders supply pre-blended, freeflowing pellets that can be reheated and foamed into products by a variety of processing methods. The pellets benefit the manufacturers such as most single-screw profilers of injection moulding companies who do not typically do their own compounding due to lack of facilities.

Other processing technique such as injection moulding and compression moulding are also used to produce WPCs, but the total tons produced are smaller (English *et al.,* 1996). These alternative processing methods have advantages when processing of a continuous piece is not desired or a more complicated shape is needed. Composite formulation must be adjusted to meet processing requirements (e.g., the low viscosity needed for injection moulding would limit wood content)

Nowadays, highly engineered WPCs are under study. These WPCs will have a better structural performance and more efficient design. Foaming technologies and multilayered profiles are under development. The current trends are also more focused on the shelf life of the WPC (Brouwer, 2000).

The advantages of composites using natural fillers as filler are listed below (Brouwer, 2000):

- Properties comparable to those of materials reinforced with glass fibre.
- Better elasticity of polymer composites reinforced with natural fillers, especially when modified with crushed fibres, embroidered and 3-D weaved fibres.
- Display acoustic insulation and absorb vibrations and large quantities of energy when subjected to destruction.

- Lower density of polymer composites reinforced with natural fibres than those reinforced with glass fibre.
- Price of polymer composites reinforced with natural fibres is from two to three times lower than that of polymer reinforced with glass fibres.

Kozlowski and Wladyka-Przybylak (2002) in their study listed a few limitations of natural fillers when applied to composites, as listed below:

- Quality production efficiency depends on natural condition.
- Non-homogeneity of natural fibrous raw materials, associated with cultivation and growing, harvesting and primary processing conditions.
- Preparation of fillers is time and labour consuming.
- Changes in properties and dimensions of polymer composites reinforced with natural fillers depend on inherent physical properties of the natural fillers.
- Large areas of cultivation, if big amount of raw materials are required.
- Low density of natural fillers can be disadvantageous in processing due to the necessity of pressure application (the fillers tend to emerge on the surface).
- Knowledge of the best properties used for composites and the best modification methods is still not sufficient.

The first generation of WPC was a combination of recycled wood flour of chips and binders and was developed for relatively undemanding applications such as decking and wall cladding. Nowadays with rapid development in material formulation and the high technology applied into the processing machine, the WPC materials are used for more demanding applications such as pillar or other structural applications.

2.3. Market of wood polymer composites

The market growth of WPC has averaged more than 25 percent a year since 1998. The market demand in North America and Europe was about 50,000 tons per year in 1995 and had increased up to 700,000 tons per year in 2002. The market growth of WPCs has been biggest in the segment of plastic industry. No other building products have reached this strong market demand (Morton, 2003).

The market leaders for WPC related products are from USA such as Trex, Timbertech and Fibre Composites. The number of WPCs supplier is growing and this will generate price pressure and rivalry of the market shares.

Decking is the most popular application of WPC. It is being used to replace traditional decking materials such as pressure-treated wood and the very durable and expensive tropical wood species. WPC decks volume is over 50 percent of total production. The most filler used is wood filler, wood flour and rice husks; on the other hand the most popular polymers used are polypropylene (PP) and polyethylene (PE). Although WPC decking is more expensive than pressure-treated wood, manufactures promote its lower maintenance, lack of cracking or splintering, and high durability. The actual lifetime of WPC profiles is currently being debated, most manufacturers offer a 10 years warranty (Caulfield *et al*., 2005).

In Europe, decking market is not as popular as in the USA but the market for WPC is in other segments such as windows, doors and product for automotive applications.

2.3.1. WPC in furniture industry

WPC has a big potential to be used for indoor furniture application. In Malaysia there are 3 companies involved in manufacturing of indoor furniture using WPC (Rosmi and Wan Saegar, 2009). Most WPC manufacturers in Malaysia are producing WPC for outdoor applications such as decking, door frame and garden furniture. Fibersit Sdn. Bhd. and CT Wood Sdn. Bhd. are examples of manufacturers that produce rice husk based WPC products applying injection moulding and extrusion processes.

According to Gobi International market report (2009_a), dining and office furniture hold RM394 million and RM49.25 million market sizes respectively for the year of 2009. The Malaysian furniture industry has emerged as a formidable industry and was ranked the tenth world's largest furniture export nation, third in Asia and second in ASEAN. The Malaysian furniture industry, being a star performer industry has an exponential growth over past two decades.

The total export of wooden furniture alone increased by an average annual rate of 13.3 % from RM2.1 billion in 1996 to RM5.8 billion in 2005 (Gobi International, 2009_b). From January to September 2008, furniture export exceeded RM6.4 billion, an increase of 1.1 %, compared to the same period last year which registered RM6.3 billion. Malaysian furniture is now being exported worldwide. Malaysian export is targeted to grow at an annual rate of 6.4 % to reach RM53 billion by 2020.

Data from the market reports show that the “green” WPC indoor furniture is commercially feasible in Asian countries such as Malaysia, and dining set furniture represents 40 % of total furniture market in Malaysia.

Driven form the huge potential in the indoor furniture segment, SIRIM Berhad through the Advanced Polymer and Composite Programmes (APCP) had carried out R&D works and was awarded a Techno-Fund grant by MOSTI in June 2007 to further explore the potential of WPC to be utilised as indoor furniture. The project focused on utilising the rice husk filler with PP matrix with filler content of at least 70 %. Figure 2.1 (a-d) below show some of the prototypes of indoor furniture developed by SIRIM Berhad researches using WPC with 70% rice husk filler.

a. WPC 4-seater dining set with solid top

b. WPC 4-seater dining set with a combination of glass top

c. WPC 6-seater dining set with a combination of glass top

d. WPC school desk and chair

Figure 2.1: Prototype of indoor furniture from WPC ("Green" Furniture project by APCP, SIRIM)

2.4. Matrix

Matrix plays an important role for the performance of the composites. The characteristics of the composites very much depend on how the matrix binds and coats the fillers. In order to make polymers more suitable for processing or end-use in a certain applications, different polymers may be blended with each other or additives may be added. Matrix is often divided into three groups, such as thermoplastics, thermoset and elastomer. In this study, thermoplastics polypropylene (PP) material is used as the matrix.

2.4.1. Thermosetting matrix

Thermosets are usually chemically cured to a highly cross-linked and three dimensional network structures. These cross-linked structures are highly solvent and creep resistant. Epoxy, phenols and polyesters are the most popular thermosets used in composites (Beg, 2007).

Advantages of thermosetting matrix:

- Thermosets have a highly cross-linked chain structure which does not allow the chains to slide and rotate easily
- This chain structure gives thermosets high strength and good stiffness properties but ductility suffers, with thermosets generally showing a brittle form of failure.
- Chemical makeup of thermosets being the most similar to natural fillers
- Production is a lot simpler, as resin moulders can be used allowing the matrix and the reinforcing agent to be cured under mild processing conditions

Disadvantages of thermosetting matrix:

- Complex formulation
- Long processing cycle
- High material cost
- Brittle (may crack)
- Require careful installation
- High installation cost

2.4.2. Thermoplastics matrix

Thermoplastics are polymeric materials which can be repeatedly melted and processed at elevated temperatures with different technique such as extrusion, compression and injection (Mali *et al.*, 2003). Polyethylene (PE), polypropylene (PP) and polyvinylchloride (PVC) are some examples of thermoplastics polymer materials.

Thermoplastics that melt or can be processed at temperatures below 200 ^{o}C are commonly used in WPC due to limited thermal stability of the wood fillers. Currently most WPC are made with polyethylene, both recycled and virgin and used for exterior building components. WPC made with wood-polypropylene are typically used in automotive applications and consumer products and is gradually being used in building and construction products. WPC made with PVC are typically used in window frame manufacturing and also in decking segment (Clemons, 2002). PP was selected as a matrix for this study due to its best combination of strength and stiffness.

2.4.2.1. Polypropylene

Polypropylene (PP) is commonly used and can be found in many applications such as packaging, stationary, textiles, households, automobiles and plastics parts. This commodity was polymerized by Karl Rehn and Giulio Natta on 1954 (Peter, 2005) and became a commercial product in 1957.

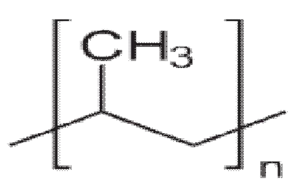

Figure 2.2: Chemical structure of Polypropylene (Wikipedia)

PP has a melting point of about 165 ^{o}C and glass transition temperature (T_g) at about -10 ^{o}C. Most commercial PP has an intermediate level of crystallinity, between 40-60 % (Joseph *et al.*, 2002). Density ranges from 0.85 g/cm^3 to 0.95 g/cm^3 depending on their crystalline. PP Young's modulus is at intermediate range. It is less tough than high density polyethylene (HDPE) and less flexible than low density polyethylene (LDPE). This allows PP to be used as a replacement for engineering plastics, such as acrylonitrile butadiene styrene (ABS) (Beg, 2007). PP also has a very good resistance to fatigue.

PP can be made by addition polymerisation process. PP can be classified by the orientation or tacticity of methyl group (CH_3). The orientation of the methyl group will determine the physical properties and the end use of the polymer. According to Billmayer (1984), polypropylene can be made in isotactic, syndiotactic or atactic form. 90 % to 98 % of commercial PP is in isotactic form.

2.5. Fillers

Fillers are particles with different types or shapes that are added to materials such as polymers, composites or concrete. The addition of filler is used for many purposes among others to reduce the consuming of matrix that is usually more expansive or to create new materials with certain combination of value. According to Brydson (1982), there are few types of fillers recognised in polymer technology and these are summarised in Figure 2.3.

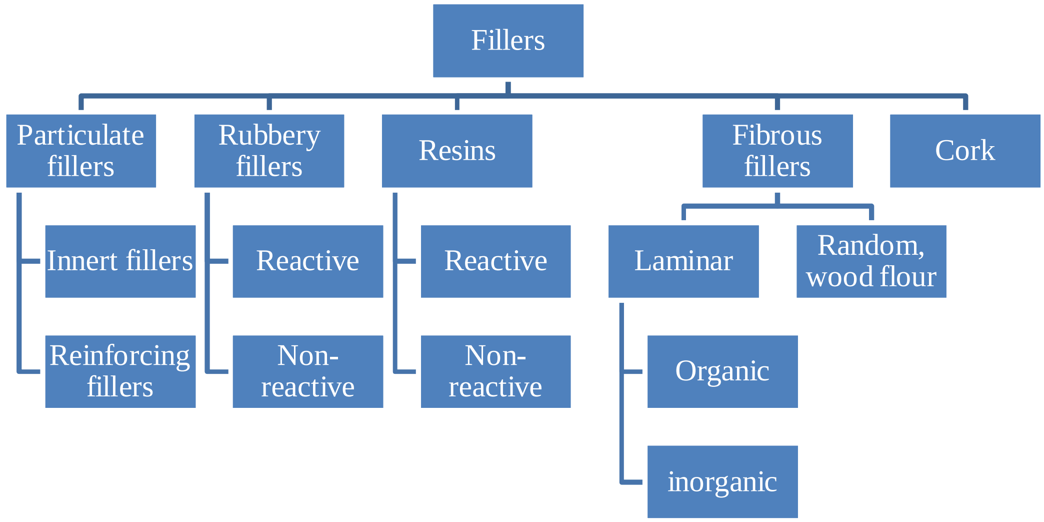

Figure 2.3: Classification of fillers in polymer compounds (Brydson, 1982)

In this study, two types of fillers are used, rice husk (RH) and sawdust (SD). Classification of fillers in Figure 2.3 divides particulate fillers into two types, inert and reinforcing fillers. According to Brydson (1982), inert filler is something of a misnomer as many properties may be affected by incorporation of such filler. The advantages of using fillers are reducing the die swell on extrusion material, increased modulus, hardness and insulation properties. Examples of fillers are calcium carbonate, china clay, talc and barium sulphate. The optimum impacts of the material properties are very much dependent on the average particle size and its size distribution, particle shape, porosity, chemical nature of the surface and impurities.

2.6. Natural fillers

Natural fillers are largely composed of cellulose, hemicelluloses and lignin with varying composition between the three items depending on the type of fillers. Chemical constituent of some natural fillers are shown in Table 2.1.

Table 2.1: The chemical constituents of some important plant fillers (Lilholt and Lwather, 2003)

Fibre	Type	Cellulose Content, %	Lignin Content, %	Pectin Content, %
Flax	Bast	65-85	1-4	5-10
Hemp	Bast	60-77	3-10	5-14
Jute	Bast	45-63	12-25	4-10
Kenaf	Bast	45-57	8-13	3-5
Sisal	Leaf	50-60	-	-
Abaca	Leaf	60	12-13	1
Coir	Seed	30	40-45	-
Cotton	Seed	85-90	-	0-1
Softwood	Wood	40-45	26-34	0-1
Hardwood	Wood	40-45	20-30	0-1

The use of natural fillers is getting popular in various industrial applications and fundamental research. These types of fillers are cheap, recyclable, renewable and biodegradable. The source of this natural fillers are abundant and can be sourced out from anywhere in this world. These natural fillers can be classified in different ways such as bast, leafs, seeds and wood (soft and hard).

Wood fillers are widely used as filler as a result of it being widely used in logging industries. The bast type of natural filler is catching up due to concerns of environmental problems. Most of the bast type of filler is sourced out from non timber plant. The chemical structure of the cellulose is shown in Figure 2.4 and Some of the natural fillers used as reinforcing element are listed below in Figure 2.5.

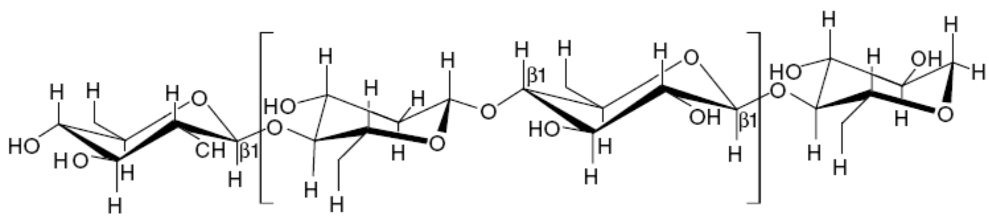

Figure 2.4: Chemical structure of cellulose (Bismarck *et al.*, 2005)

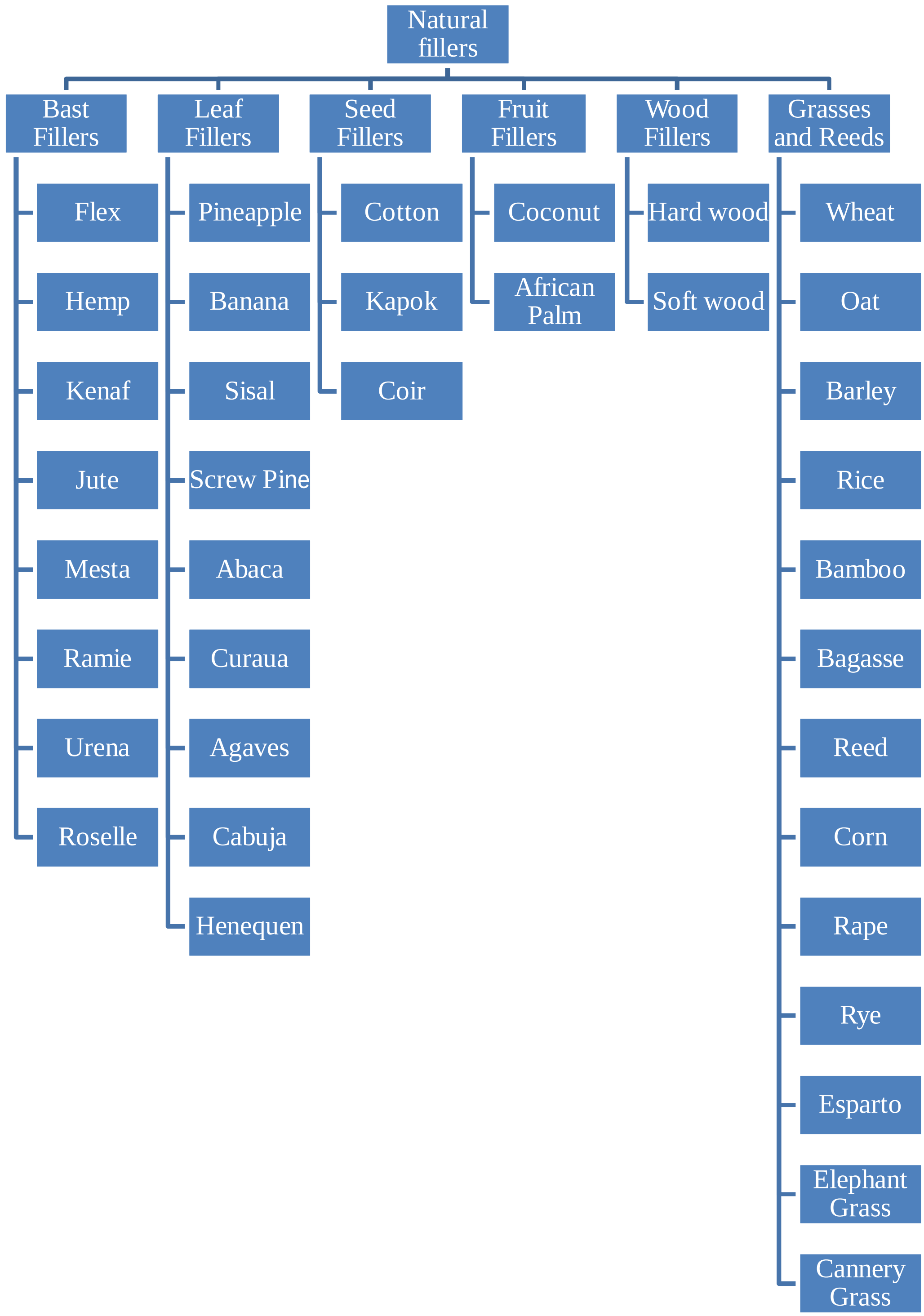

Figure 2.5: Constituents of natural fillers used as filler in wood polymer composites (Kozlowski and Wladyka-Przybylak, 2002)

2.6.1. Density of natural fillers

There is some confusion in determining density between solid wood and natural fillers. The bulk density of most natural fillers (especially wood type) is about 1.44 to 1.50 g cm^{-3} (Kellogg, 1981) but the density of the porous anatomy of solid wood cell fall between 0.32 to 0.72 g cm^{-3} at dry condition (Simpson and Tenwolde, 1999).

According to Daniel *et al.* (2005), the high pressures encountered during the processing of plastics can cause the hollow fillers of the wood flour to collapse or filled with low molecular weight additives or polymers. The degree of collapse or filling will depend on variables such as particle size, processing method and additive viscosity. Wood densities in composites approaching the wood cell wall density can be attained in high-pressure processes such as injection moulding. Consequently, adding wood fillers to commodity plastics such as polypropylene, polyethylene, and polystyrene increases their densities.

The densities of composites using lingo-cellulose as filler are considerably lower than to compare with composites using inorganic fillers or inorganic reinforcements. This density advantage is important in applications where weight is important, such as in automotive components. Recently, chemical foaming agents and microcellular foaming technology have been investigated with a view to reducing the density of wood-plastic composites.

2.6.2. Preparation method for natural fillers

The fillers especially sawdust is derived from various scrap wood from wood processors. High quality wood flour must be of specific species or species group and