SCHOOL OF MATERIAL AND MINERAL RESOURCES ENGINEERING

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Effect of Different Size of Banana Fibers on the Mechanical and Thermal Properties of Banana Fiber Filled Agar Fiberboard

By

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(Polymer Engineering)

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DECLARATION

I hereby declare that I have conducted, completed the research work and written the dissertation entitled "**Effect of Different Size of Banana Fibers on the Mechanical and Thermal Properties of Banana Fiber Filled Agar Fiberboard".** I also declare that it has not been previously submitted for the award of any degree or diploma or other similar title of this for any other examining body or university.

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Kesan Saiz Gentian Pisang yang Berbeza Terhadap Sifat-sifat Mekanikal dan Termal Papan Gentian Agar Terisi Gentian Pisang

ABSTRAK

Gentian batang pokok pisang dan agar-agar komersial telah digunakan untuk menghasilkan papan gentian pisang/agar-agar dengan menggunakan proses pengacuanan mampatan. Kesan saiz gentian terhadap sifat-sifat mekanikal papan gentian dan kestabilan terma berbanding kedua-dua gentian pisang dan agar-agar telah disiasat. Ukuran serat setiap sampel; yang dilabel sebagai Size A, Size B dan Size C, dikendalikan dengan menggunakan ayak yang mempunyai saiz mesh yang berbeza dalam proses pengisaran. Gentian pisang yang digunakan dalam papan gentian akan dikisar dan diayak dengan menggunakan ukuran anjak 100 jaringan untuk Size A, ukuran anjak 20 jaringan untuk Size B dan ukuran anjak 6 untuk Size C. Sampel yang dihasilkan telah dipotong mengikut ASTM dan sifat-sifat mekanikal mereka telah didapati hasil daripada ujian tegangan, ujian lenturan dan ujian kesan diuji. Serbuk agar-agar, gentian batang pisang dan papan gentian dari gentian pisang/agar kemudiannya digunakan untuk ujian termogravimetri analisis (TGA). Ujian tersebut telah menunjukkan bahawa kekuatan tegangan spesimen papan gentian daripada Size A (diayak oleh penapis 100 jaringan) mempunyai kekuatan yang paling rendah 11.20 MPa, diikuti oleh spesimen papan gentian Size C (diayak oleh penapis 20 jaringan) 13.62 MPa dan spesimen papan gentian Sizw B (diayak oleh penapis 6 jaringan) 14.49 MPa. Dalam ujian lenturan pula, kekuatan lenturan spesimen papan gentian Size B adalah yang tertinggi, iaitu 35.04 MPa, diikuti oleh Size A 26.13 MPa dan papan gentian Size C 35.04 MPa. Ujian hentaman menunjukkan bahawa papan gentian Size C mempunyai kekuatan hentaman yang tertinggi 15.88 kJ/m^2, diikuti oleh spesimen papan gentian

Size B 13.28 kJ/m^2 dan akhir sekali spesimen papan gentian Size A 9.659 kJ/m^2. Ujian TGA menunjukkan bahawa papan gentian dari gentian pisang/agar mempunyai kestabilan termal yang lebih rendah berbanding sampel gentian pisang dan agar-agar sahaja.

Effect of Different Size of Banana Fibers on the Mechanical and Thermal Properties of Banana Fiber Filled Agar Fiberboard

ABSTRACT

Banana tree stem fiber and commercialized agar are used to produce banana fiber/agar fiberboard using compression moulding process. The effect of fiber size on the mechanical properties of the fiberboard and thermal stability of the composite as compared to both the banana fiber and agar are investigated. Fiber size of each sample, labelled as Size A, Size B and Size C respectively, are controlled by using sieve of different mesh size in a grinding process. The fiber used in Size A fiberboard is grinded and sieved by using 100 mesh size sieve, Size B 20 mesh size sieve and Size C 6 mesh size sieve. The samples formed are cut according to ASTM and their mechanical properties are obtained using tensile test, flexural test and impact test are tested. Agar powder, banana fiber and banana fiber/agar fiberboard are then used respectively for thermogravimetry analysis (TGA) test in order to obtain their thermal properties. In the test, it is shown that the tensile strength of fiberboard specimens of Size A (sieved by sieve of 100 mesh) possess the lowest tensile strength of 11.20 MPa, followed by the Size C fiberboard specimen (sieved by sieve of 20 mesh) of 13.62 MPa and Size B fiberboard specimen (sieved by sieve of 6 mesh) of 14.49 MPa. In the flexural test, the flexural strength of the Size B fiberboard specimen is the highest, which is 35.04 MPa, followed by the Size A, 26.13 MPa and the Size C fibreboard, 35.04 MPa. In the impact test, it is shown that the impact strength of the Size C fiberboard possess the highest impact strength at 15.88 kJ/m^2, followed by that of Size B fiberboard specimen, 13.28 kJ/m^2 and that of Size A fiberboard specimen at 9.659 kJ/m^2. TGA test has shown

that the banana fiber/agar fiberboard has a lower thermal stability compared to pure banana fiber as well as pure agar sample.

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Undeniably, the rapid advancement in recent technology development in the contemporary world is largely contributed by the field of materials. Without suitable materials, it is no use to own the knowledge about the complicated design and processing method of a technology. Materials are the basic requirement of any great inventions today.

Speaking about materials nowadays, it is a rare to see any great technologies that utilize one pure material alone. The idea of combining two or more materials to be used as the basic materials of a product is neither a must for technology. Among the lists of combined materials such as alloy, polymer clays and metal-polymer product, composite in this regard is definitely one of the most useful one in the recent technology requirement. Ranging from screen of a smartphone, body of an aircraft and car, tire of a vehicle, wall of a building to household utensils and sporting goods, those utilize composite as their base materials in this century.

The extensive use of composite is mainly due to their properties, cost, ease of processibility and weight concern. For example, in terms of properties, the specific strength of a carbon fiber reinforced plastic tends to be higher than the respective values of pure aluminium or titanium. This shows that a composite component that is designed for stiffness while it also has higher safety factor against material failure than its metallic counterparts. As regard of this, when comparing costs based on volume, as well as the lower rate of failure of composite materials, it would result at a lower cost, in terms of material usage and maintenance cost. Another advantage of using composite is the possibility to tailor composites specifically for a desired function. This can be done by adjusting the fiber angle distribution or unifying the form and thus reducing the number of parts. Besides, according to Kaufmann (2008), composite structures can lower the weight of an airliner significantly. For example, the used of composite has managed to save the weight of Boeing 777 planes up to at least 1500 kilogram compared to the previously-used aluminium baseline.

Based on several advantages of composites that has been mentioned above, truly has a great advantage in the manufacturing world today. However, concerning about the materials apart, usage of synthetic fiber composites have recently become an issue due to its potential to pose a risk to the environment. One of the risks is synthetic fibers (like glass fiber and carbon fiber) are petrochemical that are non-biodegradable.

Regarding of this, natural fiber has turned out to be one of the best solutions to develop in this field. The nature provides full of resources of composite materials to be used. In fact, the nature per se, is utilizing fiber in an abundance of application, most notably is our bone. Bone is a natural composite that supports the weight of members of the body. It consists of short and soft collagen fibers embedded in a mineral matrix called apatite. Besides, parts of plants are mainly composite as well. Wood, as an instance, is a fibrous composite with cellulose fibers in a lignin matrix.

Composite aside, there are other several useful materials on this earth disposed as wastes as well. Banana tree, in this case, turns out to be one of the most enormous one. Although referred to as a “tree” the banana plant is the world’s current largest perennial herb, with each stem produces just one bunch of fruit. It is tropical herbaceous perennials in the family Musaceae. It is scientifically known as Musa X Paridasiaca. In this family, there are three genera of banana trees; Ensete, Musa and Musella. In fact, there are more than 300 varieties of bananas exist like Baby, Manzano, Burro, and Plantain. But, the global trade is abundance of one variety, the Cavendish, grown predominantly in Central America and the Philippines. The Cavendish banana is a sterile triploid. It produces fruit in the absence of pollination (parthenocarpy). Thus, it does not have any seeds. Today, the most edible banana plants belong to the Musa Acuminate, Musa Balbisiana and Musa Paradisiaca.

Banana is also a berry that is low in fat and having an excellent source of vitamins, they are Vitamin A, Vitamin B6, Vitamin C and Vitamin D. Each type of vitamins helps our body to maintain healthy in different ways.

On top of that, banana also provides various health benefits to us. Among the benefits are as listed below:

- Banana has a mild laxative property
- It is a good remedy of constipation especially in children.
- The fruit is used to heal the intestine lesions.
- Children who are malnutrition can consume banana as part of their diet.
- The core of the stem is believed to be useful in stomach upset and diabetes.
- The extracted core of the stem is considered to be useful in dissolving the stones in the kidney and urinary bladder and reducing the weight. The inflorescence mixed with coconut oil and spices is used for flushing the urinary blocks.
- Banana is able to mitigate the worm problems in kids
- It is believed to be helpful in curing diarrhea and dysentery.
- It is able to lift up one’s mood due to banana can stimulate endorphins in our brain.
- It also contains a great source of energy especially for athletes (Kumar et al. 2012).

Indeed, banana provides us with many health benefits. Thus, in the contemporary commercialized world, banana has been one of the most important parts of the global economics. Researches on the benefits of banana especially in medical use are growing rapidly as well. This, indirectly, bring about the plantation of banana trees to become more and more massive globally.

1.2 Justification

Synthetic fiber has been developed and widely utilized to fulfil the huge demands especially in manufacturing industry, polymer composite industry and construction industry. This is attributed by their light weight but high mechanical properties characteristics. However, until recently, the use of fiber is moving towards the more environmental friendly and sustainability avenue. The depleting-fast resources on this earth especially petroleum that is frequently utilized in synthetic fiber industry has become a huge concern of every earth citizens.

Fortunately, scientists and researchers from all over the globe are now working hard for another sustainable alternative. In this case, natural fibers from biological material are prominent to replace the synthetic fiber in various industries. The use of natural fiber has long been recognized and widely accepted and encouraged to be utilized for their particular properties and characteristics, especially in composite field. Unfortunately, their potential is yet to be fully discovered.

One of the most widely researched works is the making of fiberboard. A fiberboard is a type of board made by using fibers through compression process. Their marvelous properties, attractive surface appearance, biodegradable and environmental friendly characteristics makes them a potential technology to be widely used in the future in various application.

Natural fibers like cotton fiber, spider silk fiber and kenaf fiber have been widely studied and developed by researches globally. However, banana lacks of these attentions. It is renewable, easily available, light in weight, low in cost, and most notably, their wastes are always left rotten or burnt in the farm without properly reutilized. Thus, it is imperative that banana wastes would be addressed on by various authorities, to be reused in various applications like composite as banana fiber. Dominantly, banana fibers tend to be used more as a reinforcing agents but it will act as matrix in making it into fiberboard, while binder will normally be used to strengthen the interbonding between the fibers.

In this sense, binders can be classified into three types; synthetic polymer, natural polymer and sugar. Examples of synthetic polymers are methyl cellulose, polyethylene glycol, ethyl cellulose and polyvinyl pyrrolidone. Natural polymers are polysaccharides like plant cellulose, starch, gelatin, acacia, microcrystalline cellulose(modified cellulose) and gums. Sugar binders could be sucrose, xylitol, lactose and sorbitol.

Epoxy, as compared to agar, is vastly used in this case. However, epoxy is considered as synthetic polymer unlike agar. It would cause environmental pollution. Agar, on the other hand, is polymer made up of polysaccharides. It is a natural polymer binder. This type of polymers is biodegradable and they are mostly environmental friendly. However, it is yet to be investigated if agar could be used as a binder in banana fiber fiberboard, while the effect of the thermal properties after addition of fiber is an unknown as well.

The use of banana fiber binded with agar is still a very new concept. Various tests should be carried out to determine their properties, most notably, mechanical and thermal properties. Factors like different size of banana fiber or different parts of banana tree should also be studied against the effect in their properties. By doing so, it is believed that the potential of banana fiber/agar fiberboard would be greatly maximized.

1.3 Scope of Study

The study will involve the preparation of banana fiber using compression molding while agar is used as the binder. The banana waste obtained will be cleaned and processed into banana fiber before it is mixed with agar and compressed into a fiberboard, which is the main sample of the study. The precautionary steps during the preparation of the fiberboard are determined. The ratio of banana fiber to agar in the fiberboard is expected to be 1:1. However, the types of binder used such as difference between agar and epoxy will not be studied comprehensively.

The effect of different size of banana fiber in the fiberboard against the mechanical properties will be the main objective in this study. The size of the fiber will be controlled by using different mesh size of sieve (100 mesh, 20 mesh and 6 mesh) during the grinding process. After the fiberboards of different fiber size are formed, it is then tested to determine its mechanical properties such as tensile strength, flexural strength and impact strength using tensile test, flexural test and impact test. This is to determine whether the fiberboard produced has the ability in resisting these stresses and impact during its application. The thermal stability of the fiberboard produced will be compared with the thermal stability of both banana fiber and agar using

Thermogravimetric analysis (TGA). This is important to study the effect in thermal stability of the banana fiber after the addition of agar as binder.

1.4 Objectives

1. To prepare different sizes of banana fiber from banana pseudostem so as to produce fiberboard of different fiber size.
2. To produce fiberboard using banana fiber from wasted banana pseudostem fiber and grinded agar.
3. To investigate the mechanical(tensile strength, flexural strength and impact strength) and thermal propertiesof banana fiber/agar fiberboard composites.

CHAPTER 2

LITERATURE REVIEW

2.1 Composite

Basically, structural materials can be categorized into four categories, which are metal, ceramic, polymer and composite. A composite material (also called composition material or shortened to composite) is made up of two or more constituent materials with significantly different physical or chemical properties, that when combined, produce a material with characteristics different from the individual components (Johnson, 2015). Although many man-made materials have two or more constituents, they are generally not referred to as composites if the structural unit is formed at the microscopic level rather than at the macroscopic level. Thus, metallic alloys and polymer blends are usually not classified as composites (Gibson, 1994).

In a composite, the individual components remain separate and distinct within the finished structure. Mostly, a type of strong and stiff component will be present in elongated form and embedded in a softer constituent which is the matrix. For instance, wood is constituted of fibrous chains of cellulose molecules in a matrix of lignin, while bone and teeth are both essentially composed of hard inorganic crystals (hydroxyapatite or osteons) in a matrix of a tough organic constituent called collagen (Hull & Clyne, 1996). This type of composite is commonly anisotropy, where its properties differ greatly in different directions, owing to the presence of fibrous form constituent that arrange in certain directions. For example, wood is much stronger in the direction of the fiber tracheids which are usually aligned parallel to the axis of the trunk or branch, than that in the transverse direction.

In fact, composites could be made up of structural materials of different types. Majorly, the composites used in industry are steel-reinforced concrete and polymers reinforced with fibers, normally in the form of either particulate, flakes, whiskers, short fibers, continuous fibers or sheets. Composite is much more preferable to be used in recent days due to it is relatively stronger, lighter and less expensive especially when compared to traditional materials. Most of the products made by composite demonstrate great potential for their application. This will be shown by several researches mentioned in the following paragraphs that attempt to improve the potential of composites (Gibson, 1994).

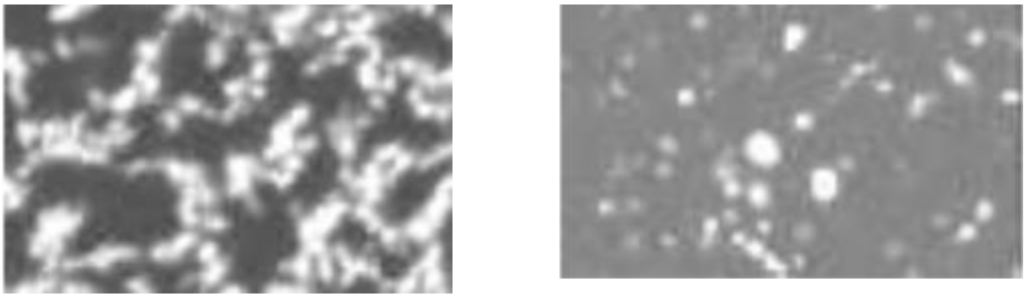
Oprisan et al. (2008) investigate the usability of a set of protective solutions based on fiber reinforce polymer composite materials, for structural elements of buildings subjected to flood loadings. These composites are made by hand lay-up forming technique utilizing glass, carbon or aramid fibers fabrics pre-impregnated with thermosetting epoxy, polyester or vinylester resins. The fiber reinforce polymer is applied in reinforce columns and beams as well as on brick masonry in order to increase the overall load bearing capacity, especially against horizontal loads. An improved protection against excessive humidity is also envisaged. A partially flooded structure is simulated by using the Finite Elements Method based LUSAS software. The numerical modeling is carried out in both the strengthened and strengthened conditions of the structure so as to evaluate the ascending in load and deformation capacities of the structural elements while volumetric finite elements are used for modeling the concrete and masonry members. As a result, it is shown that the composite is managed to improve the load carrying capacity, flexural capacity and stiffness of the construction members, masonry panels and structures made of traditional materials, when they are subjected to loading from flooding.

Quinil & Marinucci (2012) used polyurethane structural adhesives to apply in automotive composite joints. In the automobile industry, structural adhesives are frequently used for the bonding of metal substrates, thermoplastic and composites, frequently employing these in combination, particularly glass fiber and polyester composites molded using Resin Transfer Moulding (RTM) and Sheet Moulding Compound (SMC) processes. However, it is still few for the use of urethane structural adhesives in application related to composites and thermoplastics. In their study, the effects of temperature and time on the shear strength of RTM, SMC and ABS joints, are determined. This is to assess the performance under harsh conditions of use in order to evaluate if these joints could be used in passenger of off-road vehicles. The results showed that the urethane structural adhesive is able to help in the efficient bonding of the composites, considering that due to the high adhesive strength the failures occurred in the substrates without adversely affecting the bonded area.

In another research by Agarwal et al. (2013), the thermo-mechanical properties of silicon carbide filled chopped glass fiber reinforced epoxy composites are investigated. The physical properties, mechanical properties, and thermal properties of chopped glass fiber-reinforced epoxy composites are determined to understand the different between silicon carbide (SiC) with different weight percentages. Physical and mechanical properties including hardness, tensile strength, flexural strength, inter-laminar shear strength, and impact strength, are determined with the change in filler content to observe the behaviour of composite material subjected to loading. Thermo-mechanical properties of the material are investigated with the help of a dynamic mechanical analyser (DMA). From the result, it is illustrated that the physical and mechanical properties of SiC-filled glass fiber-reinforced epoxy composites are better than unfilled glass fiber-reinforced epoxy composites. Viscoelastic analysis for different compositions indicate that addition of excess SiC content results in degradation in energy absorption capacity of the material and hence overall performance of the composites, whereas adding too much (more than 10 wt.%) SiC content increases the elastic behavior of the composite.

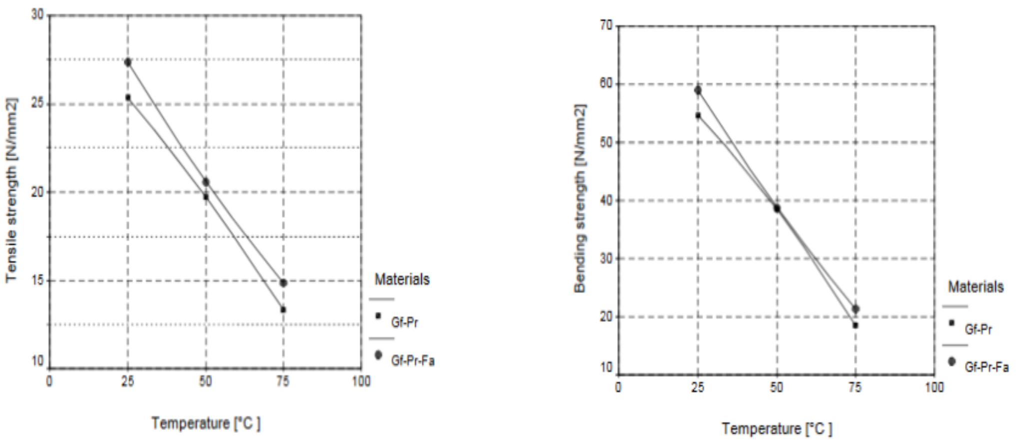
Apart from these researches, another interesting research is done by Andrei et al. (2006) regarding lightweight magnetic composites for aircraft applications. In the paper, the researchers explain that composites are widely and preferably used in aircraft industry due to their excellent properties such as light in weight, high strength, high stiffness, good fatigue life, excellent corrosion resistance and low cost manufacturing. However, composites are yet to be fully improved in terms of the thermal/electrical conductivity and the electromagnetic shielding effectiveness of lightweight composites. Generally, the engines of the aircraft tend to generate a large amount of electrical current during start up in operation. This undesirable electrical current must be conducted away by any means in order to protect the electronic device placed inside or outside the aircraft against the electromagnetic waves produced.

In their research, a lightweight composite based on combining organic matrix, reinforcing glass fibers and magnetic powders is analysed. In order to do this, two groups of composite samples are manufactured and examined. The first one is obtained in normal condition, and the second one in the presence of an external vibrating magnetic field. Analysis and test like scanning electron microscopy (SEM), tensile test, interlaminar shear strength test and bending test are conducted between the lightweight ferrite composite and standard composite. The result shown in the SEM and the mechanical tests illustrate that the new material recipe that embedded with ferrite materials can be used as a solution in solving the electromagnetic problem as mentioned above. The analysis result of SEM is as shown in Figure 2.1 while some of the results of mechanical tests are shown in Figure 2.2.



(a) (b)

Figure 2.1: Result of SEM analysis shows that (a) little air bubble found in standard composite and (b) air bubbles are scattered in lightweight ferrite composite that induced with vibrating magnetic field. The scattering air bubbles enhance the matrix interface and thus improve the mechanical properties of the composite (Andrei et al., 2006).



(a) (b)

Figure 2.2: Result of (a) tensile test and (b)bending test against temperature. Both the result demonstrates that composite material with Ferrite has a relatively better mechanical properties as compared to standard composite (Andrei et al., 2006).

2.2 Fibers

Fiber is a natural or synthetic substance that has a very high aspect ratio, where its length is dominantly longer than its radius. In industry, most reinforcements used in composites are fibers because these materials are stronger and stiffer. In this case, scientists nowadays prefer to use advanced fibers, which possess very high strength and stiffness couples with a very low density, to be used in various applications (Gibson, 1994).

Over the past few decades, polymers have replaced many of the conventional materials like metals in various applications. This happens mainly due to the advantages of polymers offer over conventional materials including processing productivity and cost reductions. In most of these applications, the properties of polymers are modified using fillers and fibers to suit the high strength or high modulus requirements with a lower cost. Fibers in these materials are the load-carrying elements and provide strength and rigidity, while the polymer matrices maintain the fibers alignment (position and orientation) and protect them against the environment and possible damage. Fiber-reinforced polymers, in this sense, are better than conventional materials when specific properties are compared. Nowadays, these composites could be easily found in everywhere ranging from household appliances to aircrafts (Gibson, 1994).

In this case, the fibers used normally can be categorized into two group, they are the synthetic fibers and natural fibers. At this century, synthetic fiber is still dominant as compared to natural fibers even though natural fibers are getting attention of scientists or researchers. The details of the two categories of fibers are discussed further in the following subtopic. In addition, hybrid fibers will be lightly mentioned in another subtopic (Gibson, 1994).

2.2.1 Synthetic Fibers

Synthetic fibers such as glass, carbon, Nylon, aramid and Kevlar fiber are man-made fibers whose chemical composition, structure, and properties are modified during the manufacturing process. About half of all fibre usage is accounted of synthetic fibers in the contemporary world with applications in fiber technology, while nylon, polyester, acrylic and polyolefin synthetic fibers are the dominant few in the market. These fibers are generally processed by extruding fiber forming materials through spinnerets into air and water, forming a thread of fibers. These synthetic fibers have improved properties of different products in various applications.

For example, Sarker et al. (2011) mention that composite consist of continuous carbon, glass or aramid fibers bonded in a matrix of epoxy, vinylester or polyester fibers are the basic load for many seismic retrofit structures. Until today, there are still a lot of structures in seismically active zones are unable to withstand seismic action. This urges a lot of researchers to upgrade and strengthen the performance of these structures. One of the best and most acceptable methods include the use of abovementioned fiber reinforced polymer to retrofit into the seismically affected structures. It is shown that synthetic fiber reinforced polymer is able to demonstrate an increase of ultimate strength of concrete beams by the range of 22% to 245%, whilst the shear strength of carbon fiber reinforced polymer retrofitted beams could be enhanced by up to 114% as compared to the similar beam without any reinforcement. From this point of view, it has shown that synthetic fiber composite is truthfully useful in seismically retrofit structures. However, care must be taken to ensure that new failure modes in the beam are introduced.

Song et al. (2005) on the other hand, investigates the strength potential of synthetic fiber nylon reinforced in concrete versus that of the polypropylene fiber-reinforced-concrete, at a fiber content of around 0.6 kg/m3. Several tests like the compressive and splitting tensile strength and modulus of rupture are done on both types of concrete. Nylon-reinforced concrete has a compressive strength 6.3%, splitting tensile strength 6.7%, and modulus of rupture 4.3% higher than those of the polypropylene fiber concrete. Nylon fiber-reinforced concrete also has a higher first-crack and failure strengths and the post first-crack blows improved more for the nylon fiber concrete than that of polypropylene in impact test. Furthermore, nylon concrete samples also have the higher shrinkage crack reduction potential. The results are showing that nylon fiber is generally better in mechanical properties than polypropylene due to it has a better distribution in concrete.

Another interesting research by Khan et al. (2010) has done research work on the mechanical, degradation and interfacial properties of synthetic degradable fiber reinforced polypropylene composites. In the research, phosphate salts of iron, sodium, magnesium, and calcium are used to synthesize the synthetic phosphate based degradable fiber. 10% by weight of the fiber is then laminated into polypropylene (PP) matrix in unidirectional to fabricate the composite. After the tests are conducted, it is found that the tensile strength, tensile modulus, bending strength, bending modulus, and impact strength are 38 MPa, 1.5 GPa, 44 MPa, 4.9 GPa, and 7.58 kJ/m^2 respectively. However, these mechanical properties only retain approximately 80% of their original properties after six months of degradation tests of the fibers and composites. The test is conducted in aqueous medium at room temperature. To obtain the interfacial shear strength, a single fiber fragmentation test is performed. From the result, it is observed that the phosphate based synthetic fiber reinforced composite shows good fiber matrix adhesion, with the tensile strength of 5.9MPa.

In fact, synthetic fiber is still having a great potential in the composite industry. However, it is currently often labelled as non-environmental friendly and thus it is not used as fibers in this paper. Natural fiber owns the advantage in this sense, which will be discussed in the next subtopic.

2.2.2 Natural Fibers

In certain composite applications, natural fibers have shown to be as useful as glass fiber. For centuries, natural cellulose and protein fibers were frequently used to make into clothing that almost entirely derived from dedicated sources. Planting of fiber crops and rearing of sheep as well as silkworm were once the conventional ways of obtaining cellulose and protein fibers, respectively. In this sense, it is rather clear crops plantation were not just major sources of food like cooking oil and animal feed but it is a good source for clothing as well. Among the different types of fibers, natural cellulose fibers, mainly cotton, have been the most common source for fibers in the past centuries. Lately, the production of cotton and other natural fibers are gradually declining due to the difficulties in growing cotton, higher earnings from biofuel crops such as corn and soybeans, and limited advancement in technology to process and to use cotton-based textiles commercially. Similarly, the concern of depletion of petroleum resources required for synthetic fibers has been a hot issue being discussed to be aware of recently.

These factors lead scientists and researches attempting to look for other alternatives in the coming future.

In fact, a lot of researches had been done to uncover the potential of other natural fibers. One of the examples will be spider silk. According to Ning et al. (2006), spider silk fibers are highly potential in replacing synthetic fiber due to its high strength and toughness. It is a composite material with a hierarchical structure, composed mainly of two proteins, Spidroin I and II. In the article, it is reported a new model of the hierarchical structure of silk based on scanning electron microscope and atomic force microscope images. It is found that the protein polypeptide chain network structure of spider silk changes substantially with reeling speed. The structure shows beta-sheet, polypeptide chain network and silk fabril. The result is found that an exceptionally high strength of spider silk can be obtained using Instron Microtester by reducing the size of the crystalline nodes in the polypeptide chain network while increasing the degree of orientation of the crystalline nodes.

On top of that, green composites made out of natural fiber namely bamboo fibers embedded into biodegradable resins are produced with press molding by Cao & Wu (2008). In this context, the tensile strength of green composites is investigated while the statistical strength and distribution of bamboo fiber are also analysed on the basis of the Weibull distribution and the weakest-link theory. The result illustrates that the tensile strength of this bamboo fiber reinforced composites is about 330 MPa with the fiber volume fraction of 70%. This value is close to or higher than that of other natural fiber reinforced green composites. In addition, the tensile statistical strength of fiber shows that it fits well with two-parameter Weibull distribution.

Another review on Bombyx Mori natural silk fibres are done by Ude et al. (2013). Bombyx Mori cocoon has been the provider of silk for the textile industry for over 400 years. The silk produced consists of two different protein based layer, fibroin in na inner layer and a sericin coating in an outer layer, which is an amorphous protein polymer that is capable to act as adhesive binder to maintain the structural integrity of the fiber.

In the review, it is suggested that the Bombyx Mori silk fibre is one of the best fibres discovered that possesses better mechanical properties like Young's modulus, shear modulus, yield stress, tensile deformation behaviour and tensile breaking strain over those common natural fibres like sisal, jute, hemp and coir. However, the mechanical and physical properties of the Bombyx Mori Silk Fibre are depending on several factors. These factors are its original source, orientation, age, which will affect the structure and properties, processing methods, fibre length, fibre orientation, fibre volume fraction as well as the experimental conditions, such as temperature, fibre diameter and fibre surface treatment. Different matrix arrangements, too, will result in different properties. Fibre surface treatment of Bombyx Mori Silk with silane is capable to improve the adhesion properties between Bombyx Mori Silk and matrix, while enhance the fracture toughness of the composite. In fact, one major setback for the composite of this silk fiber is that they are actually has a low resistance in dynamic loading of foreign objects. Currently, the fiber is mainly used as textiles industries, tissue engineering, suture material in biomedical industries as well as reinforcement in composites. Bombyx Mori silk fiber has also been introduced as reinforcement in different polymeric matrix for automotive applications.

Tanasa et al. (2015) also attempted to synthesize zinc oxide(ZnO) composites filled with linen fiber, another plant-based natural fiber. The morphological, structural, chemical and humidity adsorptive attributes of the composite are evaluated. The main factor and characterizing aspect of the study involves the effectiveness of ZnO-linen fibrous composites synthesized through hydrothermal deposition of zinc oxide onto linen fibrous substrates that are previously grafted with MonoChloroTriazinyl–β-CycloDextrin (MCT-β-CD) with the assistance of two surfactants. This is done via hydrothermal process. Scanning Electron Microscopy (SEM) image is used to examine the morphology, Energy-dispersive X-ray spectroscopy analysis (EDX) for surface composition while Fourier Transformation Infrared (FTIR) spectroscopy and X-ray diffractometry for structural samples features. Lastly, Dynamic vapour sorption (DVS) analysis is also done to complete the study. The results of the study demonstrated that the uniformity of the fabric coated with ZnO powder hydrothermally synthesized with help of Cetyl TrimethylAmmonium Bromide (CTAB) is better than that of ZnO powder hydrothermally synthesized in the presence of Pluronic P123 and provides good washing fastness. The results from X-ray diffraction have shown that the composites exhibited a more ordered structure and higher water vapour sorption-desorption capacity (obtained by DVS analysis) as compare with those of the reference fibrous linen supports. This research could be considered as another breakthrough potential in natural fiber composite technology.

Besides, Ticoalu et al. (2013) studies Gomuti fiber, a natural fiber obtained from Arenga Pinnata tree, about their physical, mechanical and thermal characteristics to observe its viability as natural fiber composite material. The research entails observations of fiber morphology, diameter, density, single fiber tensile testing as well as the fiber thermal stability. Equipments like Optical Microscope, Dynamic Mechanical Analysis (DMA) machines and Thermogravimetric Analysis (TGA) instrument are used to obtain the results. The results show that the black in colour gomuti fiber has a coarse physical appearance, with diameter in a range of 81-313 μm, with an average of 168 μm, while the density of gomuti is around 1.40 g/cm^3. The mechanical properties of single gomuti fiber are also determined. The average tensile strength is at 173.9 MPa and the average elastic modulus is 3847 MPa, which are duly high. Other batches of gomuti fiber samples are undergone alkali treatment where different concentrations of sodium hydroxide (5% and 10%) are used to modify the fiber's characteristics. From the results, it shows that treated gomuti fibres demonstrate different diameter range, density, single fiber tensile properties and different thermogravimetric plots as compared with non-treated gomuti fibers. For example, the alkali treated specimens (5% and 10%) exhibit reduced number of tyloses on the fibre surface. The surface of 10% alkali-treated specimens is almost clear of tyloses, which indicates that the treatment is able to remove the tyloses and other impurities. However, if compared to other natural fibres, the properties of gomuti fibre obtained resemble to coir (coconut husk fibre) with relatively lower tensile strength, larger diameter and distinctively higher elongation-at-break. There is still a lot of room to improve in the research in gomuti fibers.

In fact, each types of natural fibers has different characteristics and typical properties. Above-mentioned natural fibers aside, banana fibers are actually one of the most widely used natural fibers in the current composite field. Further researcherworks or information will be discussed in another topic.

2.2.3 Hybrid Fibers

As an addition, the composite industry has discovered the use of hybrid fibers lately as reinforcement of composite. A hybrid fibers reinforced composite is composite that contains two or more type of fibers, no matter both natural fiber and synthetic fiber or both fiber from the same category. As an example, in a research by Al-Mosawi (2012), a hybrid bio-composite is used, where several fibers of different types are embedded into a single matrix. This is done so as to achieve a more favourable balance between the inherent advantages and disadvantages of both the natural fiber and synthetic fiber. In this research, araldite matrix composites reinforced with hybrid palms-kevlar fibers are used and its mechanical properties are evaluated. From the result, it indicates that the incorporation of both fibers into a single matrix which is araldite resin is able to stabilize mechanical properties and lower the cost of manufacturing. In this research the mechanical properties including the impact strength, tensile strength, flexural strength, and hardness are investigated for composite material reinforced with hybrid fibers for palms and Kevlar. These fibers are mixed with araldite resin in different reinforcement percentage (20%, 40%, and 60%) while their mechanical properties determined. As a result, it is shown that these mechanical properties significantly improve after reinforcement by fibers. The value of mechanical properties is enhanced with higher percentage of reinforcement. These results illustrate that hybrid fibers reinforced composite possess great potential in the composite industry as well. However, as for simplicity reason, only single type of fiber will be used in this paper to ensure that the properties of the particular type of fiber (banana fiber) are accurately determined.

2.3 Composite Forest Products

Composite forest products are a type of composite made of cellulose-contain products that are engineered to be glued together. For example, plywood, blockboard, fiberboard, particleboard, and laminated veneer lumber are the most common composite forest products that could be found in the market. Most of these products are made intopanel and they are normally based on wasted wood material or little used or non-commercial species. This type of material is generally known as one of the most environmentally responsible material due to wasted products are recycled while little or no greenhouse gas will be produced in the manufacture of the products while being good in mechanical properties. Thus, it can be observed that a lot of researches have ventured into the development of these products.

2.3.1 Fiberboard

One of the most common example of composite forest products is fibreboard, which is the one used in this paper. Generally, a fibreboard is a panel made up of lignocellulosic fibers embedded with a type or more synthetic resin or other suitable bonding system and bonded together under heat and pressure.

In a research work by Halvarsson et al. (2010), it has shown that the manufacture of high performance rice straw fiberboards. A thin medium and high density of fiberboards are to be produced. Firstly, the rice straw is cleaned, cut, grinded, and soaked in water before refining. Defibration is then carried out in a pressurized pilot-plant single-disk refiner, OHP 20''. The fiber produced is analysed and it is shown that it has an average fiber liength of around 0.9mm, an average fiber width of 31 μm, a shive weight of below 24%, and a dust content of less than 30%. Then, 3%, 4% and 5% of methylene diphenyl diisocyanate (MDI) is added into fibers respectively to form the fiberboards. The processes are as shown in Figure 2.3. Tests include the flexural properties, internal bond strength and thickness swelling of the produced rice straw and MDI resin are done and they show excellent result. The internal bondalso reaches 2.6 MPa, while both the modulus of rupture (MOR) and Modulus of elasticity

(MOE) show a level better than general fibreboard requirement for interior applications. Apart from that, the water-repelling properties of the 3-mm rice-straw fiberboards are fairly good while the thickness swelling (TS) is around 20%. Additionally, it is investigated that to avoid adhesion between the compression plates and the fiber material during hot pressing process. Two different methods that work include applying protective paper sheets between the fiber mat and press plates and spray release agent on steel plates. No adhesion is observed between the compression steel plate and the fibreboard.

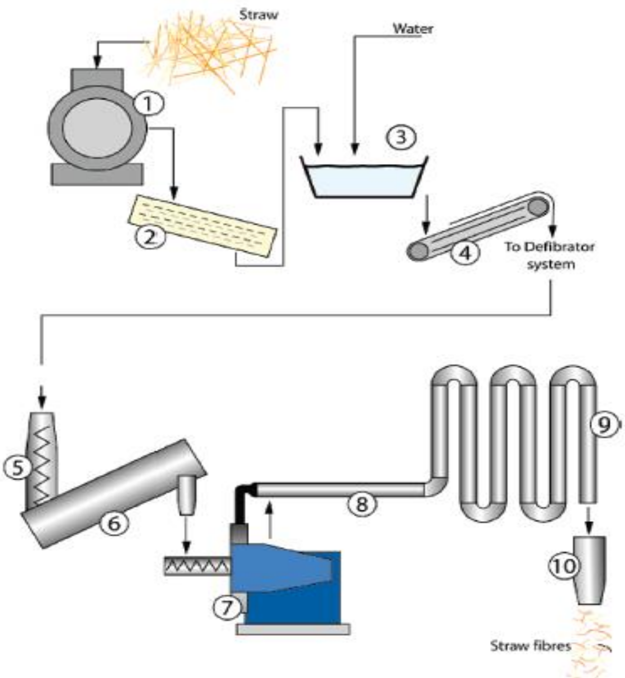


Figure 2.3: Schematic of rice-straw fiber preparation system in an MDF pilotplant: (1) hammer mill, (2) dry screen, (3) soaking in water, (4) conveyer,(5) infeed screw, (6) preheater (digester), (7) defibrator (refiner), (8) blowline(no addition of adhesive), (9) dryer, and (10) fiber outlet (cyclone).

Ashori et al. (2009) utilize sugarcane bagasse fiber to manufacture medium density fiberboard (MDF). The objective of their research is to study the effects of maleic anhydride (MA) and compressing temperature on the mechanical and physical properties of the fiberboards produced. Highest values of mechanical properties like internal bonding, static bending and MOE are observed in the fiberboard compressed at temperature of 190 ℃ among the other types of fiberboards sample. Besides, the fibers also show minimum steam absorption at the similar condition in time of 12 hours while no samples show additional absorption of steam after 120 hours of steam treatment. However, thickness swelling values are higher than requirement. Thus, it is learnt that additional works is needed to improve the physical properties from sugarcane bagasse fiber.

From these researches, it is shown that fiberboard is highly potential in the future market and there are more room of improvement to make the panel better. Other than that, resin used to bind the fiber together is also a concern for the environment especially when synthetic resin is used. This will be further discussed in another topic.

2.3.2 Other Types of Composite Forest Product

Bekhta et al. (2008) has investigated the properties of plywood manufactured from compressed veneer as building material to replace those traditionally manufactured plywood panels. In this study, the physical and mechanical properties of plywood produced from compressed veneer of birch (Betula pubescens) and alder (Alnus glutinosa) using a cold rolling process are evaluated. A total of 100 defect samples with dimension 300mm by 300mm and thickness of 1.3mm and 1.5mm are moisturize to about 8%. Densification using a rolling device is then done to reduce the time of pressing, pressure of pressing, tem-perature of pressing and glue spread beforetests like mechanical properties tests (shear strength, bending strength and compression strength), surface roughness test, tensile strength parallel and