

Biodegradable Bast Fiber-Based Composites



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Abstract Recently, the using of plant-based fibers especially bast fibers has been investigated as substitutes for the synthetic fibers such as aramid, carbon, and glass in the polymers composites as reinforcement because of their lightness, biodegradability, low cost, and high mechanical behaviors. Biodegradable composites are defined that a biodegradable polymeric matrix is reinforced with biodegradable fibers. Biodegradable polymers are known as the polymers degraded with enzymes. In order to produce a biodegradable composite, plant-based fibers are frequently used. The behaviors of these composites are fundamentally dependent on the fiber kind, aspect ratio, orientation of fibers in the matrix, volume fraction, and adhesion of fibers and matrix. Especially, fiber properties affect the biodegradable composite behaviors. The plant-based fibers are mainly categorized into grass bast, leaf, seed, and straw fibers. In plant-based fibers, bast fibers are obtained in the bast of plant and it is known that these fibers have been utilized by earlier civilization. Common examples of bast fibers are jute, ramie, kenaf, flax, hemp, and bagasse. Because these plants are annual crops, they are getting rising interest in a variety of biodegradable composite production processes. This chapter, it is reported an overview of the current investigation of biodegradable materials. These consist of some developments substantiated in the field of biodegradability, biodegradable polymers biodegradable composites, bast fibers, and biodegradability testing methods. This chapter could help in the investigation of this area and using of composites in industries.

Keywords Biodegradability · Biodegradable polymers · Biodegradable composites · Bast fibers

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1 Introduction

Biodegradation is commonly described as the degradation of organic substances by enzymes produced by living microbial organisms to small components. Organic substances are transformed through metabolic or enzymatic processes. Although the biological degradation process varies generally, the last product of biological degradation is commonly biomass, methane, and carbon dioxide. Organic sustenance can biodegrade in oxygen (aerobic) or anaerobic environments without oxygen. Aerobic biodegradation is defined as organic substance degradation with microorganism in the presence of oxygen in the environment. Aerobic biodegradation is characterized by oxidative conditions. A variety of organic pollutants are decomposed rapidly under aerobic conditions by aerobic bacteria (aerobes). Aerobes have an oxygen-based metabolism and utilize oxygen to oxidize substrates (sugars and fats) to obtain energy in a process called as cellular respiration. Before cellular respiration, glucose molecules are degraded into two small molecules. This occurs in the cytoplasm of aerobes and then these small molecules enter the mitochondria. In the degradation of small molecules into H_2O and CO_2 , oxygen is used, and energy is also released due to the reaction. Aerobic degradation does not release pungent-smelling gases unlike anaerobic degradation. The aerobic process also improves the environment of workers and animals and helps keep pathogens under control. Anaerobic biological degradation (without oxygen) occurs when the number of anaerobic microorganisms is higher than aerobic microorganism. Biodegradable wastes are degraded without oxygen. Compared with aerobic and anaerobic degradation, it is a widely used method for the treatment of wastewater and biodegradable wastes, as it allows us to reduce the volume and mass of input materials. Anaerobic biodegradation is a renewable energy source. In this process, biogas is produced including methane and carbon dioxide for suitable energy production. In addition, nutrient-rich solids left behind after decomposition can also be used as fertilizer [1].

Biodegradation is a commonly microbial natural process that regenerates biological fundamental elements within the World's biogeochemical cycles. Biological degradation is generally catalyzed by enzymes which are converted chemicals into the last product. A chemical substrate is converted to entirely oxidized products by enzymes, and this process is called as mineralization. Biotransformation consists of the conversion of a chemical substance into another without whole mineralization and is shown commonly during microbial metabolism of synthetic substance [2].

In the words, a variety of wastewaters including organic substances are drained. Bio-treatment is accepted to be the well-liked treatment; however, all the wastewaters cannot be applied by bio-treatment for economic or technical reasons. Therefore, the biodegradability of wastewater or substance is needed to evaluate before biological application. In order to determine of biodegradability of a substance, many methods have been provided. When organic substances are degraded by microorganism, basic inorganic substance occurs which are H_2O , CO_2 , and energy delivery. Microorganisms utilize energy to transform ADP into ATP. It then uses the energy from the

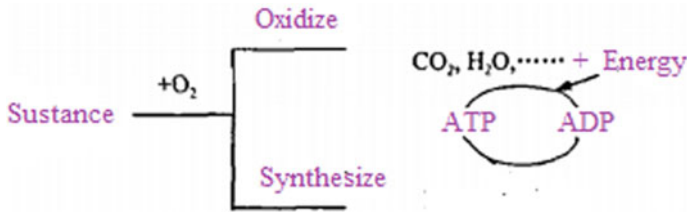


Fig. 1 The degradation of organic substance

reaction of hydrolysing ATP to synthesize the new cytoplasm on the other side. The degradation of organic substance is given in Fig. 1 [3].

Plastics are used in many fields due to their advantages. However, the demand for using and development of biodegradable materials have increased in approximately all industries in recent years. Biodegradable polymers can degrade with the enzymatic activities of bacteria, fungus, and algae in a bioactive environment. As a result of the biodegradation of biodegradable materials polymers turn into CO₂, CH₄, biomass, water, humus, and other natural substances and do not cause environmental problems in any way.

Biodegradable polymers are classified as primary, seconder, and tertiary generation polymers. Primary generation polymers involve the mixture of low-density polyethylene, 5–10% starchers, and pro-oxidative and auto oxidative of additives. During the production of primary polymers, starch granules are blended homogeneously into low-density polyethylene. During the mixing process, microbial degradation of starch results in losses in the properties of low-density polyethylene films. At the same time, low-density polyethylene undergoes chemical degradation with oxygen. First-generation biodegradable polymers are not considered as biodegradable since it takes 3–5 years to degrade in the soil. Second-generation polymers comprise of ethylene acrylic acid, vinyl acetate, and hydrophilic copolymer additions such as polyvinyl alcohol, low-density polyethylene, and gelatinized starch. These polymers degrade for 2–3 years. Tertiary biodegradable polymers consist of fully biobased materials and are synthesized from biomass monomers by classical chemical synthesis. Furthermore, polymers extracted directly from biomass are also used in the tertiary biodegradable polymers. In addition, polymers produced by natural or genetically modified microorganisms are also used in the production of biodegradable plastics [4].

Polymers have been used in almost all industries such as the textile industry for the production of synthetic fibers. Synthetic fibers have been utilized in the textile industry for many years. In literature, it is reported that synthetic fibers lead to skin irritation for the users, environmental pollution, and abrasion to the devices. Especially, because of environmental pollution, researchers, and engineers have focused on the development of alternative sources to synthetic fibers and many natural fiber sources have been investigated. Natural fibers have many advantages which are highly specific stiffness and strength, non-abrasiveness, low cost, sustainability, easy manufacturing, biodegradability, and abundant availability. The disadvantages of natural

fibers are reported as brittleness, moisture absorption, low processing temperature, and incompatibility with polymers [5].

This chapter presents an overview of current literature compared of biodegradable materials. The aim of this chapter is to throw light on the biodegradability, biodegradable polymers, biodegradable composites, and bast fibers. This could help in the investigation in this area and using of composites in industries.

2 Biodegradable Polymers

In the polymer market, most of the polymers are originated from non-renewable and non-sustainable petroleum. Moreover, it is reported that the production of petroleum from biomass takes 106 years. Because of biodegradable and renewable composite production, polymeric matrix and reinforcement must be reproduced from the regenerated resource, commonly produced from plants that are cultivated in a period of less than a year. Commonly, these materials biodegrade in a year and time to degrade of some biodegradable materials are given in Table 1 [6].

The usage of the topic of biodegradable fiber and polymer started approximately three decades ago. Most of the research has investigated biodegradable metrics,

Table 1 Time to degrade in the environment for some biodegradable materials

| Material | Time to degrade |
|--|-----------------|
| Cotton | 1–5 months |
| Poly(caprolactone)-g-maleic anhydride/starch | 2 months |
| Poly(caprolactone)-starch | 2 months |
| Waste gelatine/poly(vinyl alcohol) | 1 month |
| Waste gelatine/sugar cane bagasse | 1 month |
| Conventional copy paper | 1 month |
| Waste gelatin | 1 month |
| Waste gelatine/poly(vinyl alcohol) | 1 month |
| Waste gelatine/sugar cane bagasse | 1 month |
| Waste gelatine/sugar cane bagasse film | 1 month |
| Wool stocking | 1 year |
| Bamboo stick | 1–3 years |
| Chewing gum | 5 years |
| Painted wood | 13 years |
| Plastic | 450 years |
| Glasses and tyres | Uncertain time |

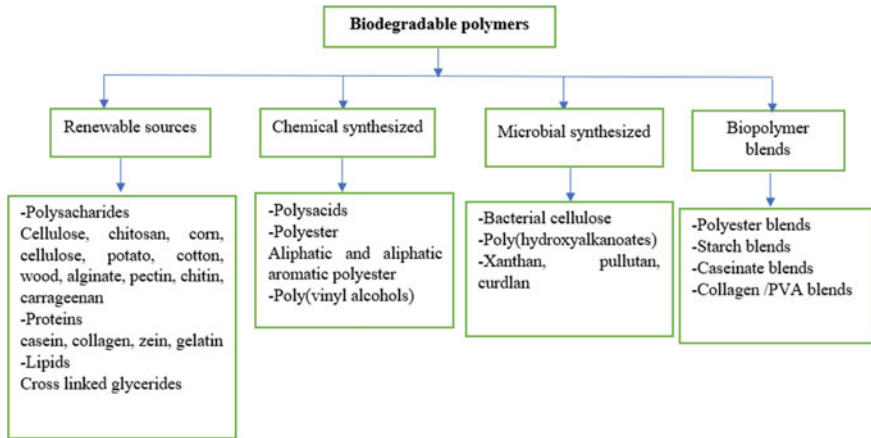


Fig. 2 The basic classification of biodegradable polymers

lignocellulosic fibers, fiber and matrix compositions, fiber extraction, biodegradable composite production, cost, mechanical and physical properties, chemical compositions, challenges, and trends [6].

The basic classification of biodegradable polymers was given in Fig. 2.

3 Biodegradable Composites Reinforced with Bast Fibers

In the present times, there has been an increasing demand for raw materials achieved from regenerated, biodegradable, and sustainable resources, fundamentally due to the growing concern about the protection of recycling and natural sources. The manufacturing and utilization of plastic substances causes many problems regarding waste disposal owing to their environmental determination. Furthermore, the production of traditional composite structures obtained from non-biodegradable plastics reinforced with inorganic fibers is evaluated critically due to the rising environmental consciousness. Researchers have focused on the development of polymers that can degrade easily. In literature, biodegradable substances which are poly(ester amide)s, poly(vinyl alcohol), poly(lactic acid), polyester, starch, starch derivatives, polyhydroxyalkanoates, and cellulose have been researched for the manufacturing of composites reinforced with natural fibers. Many advantages are reported with the utilizing of natural fibers which are low density, high mechanical stability, low cost, lack of hazardous, and relative abundance. Bast fibers, such as flax, jute, ramie, kenaf, hemp, and sisal, are the most frequently utilized as reinforcement in polymer composites and for industrial treatments [7]. A variety of researchers have investigated the characterization of natural fiber reinforced composites. The mechanical behaviors, cultivation conditions, fiber dimension and morphology, fiber aspect ratio,

the disruption and orientation of fibers in the matrix, moisture absorption, and matrix-fiber adhesion effect on the composite properties [8]. There are many different fibers that can be utilized in the development of biodegradable composites especially bast fibers. The main ingredient of these fibers is cellulose, and the fundamental unit of a cellulose macromolecule is anhydro-D-glucose which includes hydroxyl groups. These hydroxyl groups in the macromolecule lead to making all the natural fibers hydrophilic [9].

Bast fibers comprised of cellulose, hemicellulose, and lignin are obtained from the outer bark of the plant. These fibers are formed from cellulose fibrils held together with hemicellulose and lignin. Every fibril includes a complicated structure and a thin major wall surrounding a secondary wall, which affects the mechanical behaviors of the fibers. The mechanical behaviors of these fibers are related with polymerization degree of cellulose, cellulose content in the fiber, and microfibril angle [9]. In order to produce a biodegradable composite, many matrix polymers and bast fibers are used and some of these polymers are introduced below.

3.1 Bast Fiber

At the present time, sustainable and renewable sources attract attentions in the world, and many comprehensive research have been carried out through worldwide. For this reason, characterization, and preparation of bast fibers are a crucial development and research area. In light of this information, many novel bast fibers have been comprehensively investigated [10].

Bast fibers may be described as those extracted from the outer cell layers of the stems of different plants. Among the plants utilized for cultivation of bast fibers are jute, ramie, flax, and kenaf. Because these plants are annual crops, they are getting rising interest in a variety of nonwood composite production processes. Bast fibers involve a bundle of tube-like cell walls. Every cell wall consists of primary and secondary S1, S2, and S3 layers [11]. A variety of bast fibers are reported in the literature, and some bast fibers and properties are abstracted below.

***Thespesia populnea* tree fiber:** *Thespesia populnea* (T.P.) tree belongs to the Malvaceae family. This tree is cultivated in Tamilnadu, India. *Thespesia populnea* tree fiber has 52.2 wt% cellulose, 20.5 wt% hemicellulose, and 20 wt% lignin. The crystallinity index of the fiber is reported as 41%. The TGA analysis indicates that these fibers are stable at 210 °C [5].

Jute fiber: Jute fiber is extracted from the *Corchorus* plant and belongs to the Malvaceae family. Jute fiber is identified as a lignocellulosic fiber that is partially wood and textile fiber. The fibers are obtained from the skin or bast of the plant. The chemical composition of jute is reported as 64.4% cellulose, 12% hemicellulose, 11.8% lignin, 0.2% pectin, 10% water, 0.5% wax, and 1.1% water-soluble. Jute fiber has a variety of cells which are the microfibrils based on cellulose. These cells are connected with amorphous hemicellulose and lignin. Jute fibers are completely recyclable and biodegradable, and eco-friendly materials. These fibers have high

thermal and acoustic insulation capacity. It is reported that the annual worldwide manufacture of jute fiber is about 3.2 million tons and these fibers have been utilized in many fields. The bag cloth industry has a high demand for jute fibers. In the world, jute bags have increased in popularity compared with nonbiodegradable poly bags that are produced from petroleum-based polymers. However, a variety of jute fibers is wasted either in the form of jute cloth or bag every year. For this reason, researchers have investigated of the recycling of jute production [12].

3.2 Okra Fiber

Okra bahmia (*Abelmoschus esculentus*) is an herbaceous plant belonging to the Malvaceae family, cultivated mainly in the tropical countries. Okra bahmia (*Abelmoschus esculentus*) bast fiber includes 60–70% cellulose, 5–10% lignin, and 15–20% hemicellulose gain from the stem of the okra plant. In the world, vegetable of plants is collected and another part of the plant is an agricultural waste product. After the collecting of vegetables, there are many waste products. For this reason, okra fiber could be a significant source of natural fiber for various applications. Furthermore, okra fiber has high mechanical properties, sustainability, and biodegradability. It has been used as reinforcement material for composites as an alternative to synthetic fibers [13].

3.3 Flax Fiber

The flax plant has approximately 80 cm height fibers all along the stem. Flax fiber is obtained from the stem or bast of the flax plant. These fibers are founded in the form of filaments which are arranged circularly around a central wooden cylinder. Flax fiber is a cellulosic, natural, and multi-cellular bast fiber that has a 40–80 μm diameter. Flax is an attractive fiber because of having high mechanical properties, low density, biodegradability, and availability. In the present day, flax is a luxury fiber that has limited manufacturing and high cost. These fibers are commonly used to produce warm weather, professional wear, and high fashion aspects [14, 15].

Kenaf fiber: Kenaf fiber is extracted from the kenaf plant and belongs to the *Hibiscus cannabinus* L. family. Kenaf filaments commonly include 2–6 mm individual fibers. Characteristic properties of fibers can vary from the environmental condition, age, separating technique, source, and fiber history. Kenaf fibers consist of 60–80% cellulose, 20% moisture, and 5–20% lignin, and the fibers have high mechanical properties [16].

Hemp fibers: Hemp originated in central Asia and has been known for 12,000 years. The plant is cultivated commonly in China, Central Asia, Europe, and the Philippines. The fibers occur in the stem tissue which keeps the plant erect. For this reason, the fibers are high strength and stiffness. Hemp is the most used

plant-based natural fiber for reinforcement after sisal fiber due to its high mechanical strength, sustainability, biodegradability, and ecologic. In 1941, hemp fibers were utilized as reinforcement for the body of the Henry Ford car; however, the car did not produced commercially because of economic limitations. During the Second World War the production of synthetic fiber reinforced composites increased, but ecological concerns eventuated in interest in natural fiber reinforced composites again [17].

Kusha fibers: Kusha grass is cultivated in Asian countries, and kusha fiber is obtained from kusha grass. It is reported that kusha fiber comprises of 70.58% cellulose, 14.35% lignin, and 1.52% wax. The density of fiber was measured as 1.1025 g cc^{-1} . X-ray diffraction analysis reveals that the crystallinity index of fiber is 55.4%. Thermogravimetric analysis shows that the fibers are stable up to $357 \text{ }^\circ\text{C}$ [18].

***Pennisetum Purpureum* fibers:** *Pennisetum Purpureum* belongs to the Poaceae family called as Napier grass. This plant is cultivated in tropical and subtropical regions worldwide. *Pennisetum Purpureum* fibers were extracted from this plant and the fibers have 54.26% cellulose, 18.85% hemicellulose, 25.33% lignin, and 5.93% water. Thermal stability occurs in the ranges of $120\text{--}330 \text{ }^\circ\text{C}$. The fibers have high mechanical behaviors [19].

4 Biodegradable Matrix Polymers

Polymeric materials can be produced from regenerated sources such as plant cellulose fibers, vegetable oil, bacteria as well non-regenerated petroleum (polyester). Biodegradable polymers can be classified as origins that are natural or synthetic. Furthermore, these polymers can be categorized based on their origins such as agro polymers (cellulose or starch), microbial (poly(hydroxyalkanoate)), polymers synthesized from agro-based sources (poly(lactic acid)) and synthesized from conventionally synthesized monomers. Some of the most used matrix polymers were introduced below.

Poly(butylene succinate): Poly(butylene succinate) is one of the biodegradable polymer which is synthesised with butanediol and succinic acid. These two polymers originate from bio-based regenerable sources. PBS, which is a thermoplastic polymer, has melting point at about $90\text{--}120 \text{ }^\circ\text{C}$ and glass transition temperature of about $-10 \text{ }^\circ\text{C}$ to $-45 \text{ }^\circ\text{C}$. Moreover, PBS is known as commercially available, biodegradable, high thermal and chemical resistance. However, softness, high price, and gas barrier properties limit the application of PBS. Due to decreasing of the PBS limited usage, PBS is reinforced with natural fibers which are low density, high mechanical properties, low cost, sustainable, renewable, and biodegradable [20].

Poly lactide: Polylactide (PLA) is a biodegradable polymer generally synthesized cyclic lactide dimer. PLA can be manufactured with polycondensation of lactic acid. In the second way of PLA production, PLA is achieved with low molecular weight. The raw material of PLA is a renewable natural product which is obtained from corn starch. PLA polymer is commonly used in commercial packing material due to

regenerated and having good mechanical properties. However, some disadvantages which are high prices and brittle character in thicker material limit the usage of PLA compared with other thermoplastic polymers [9].

Starches: Starches produced with conventional methods are natural hydrophilic polymers. Starches have low melt processability and are high hydrophile, for these reasons, a plasticizer needs them to make them suitable for using engineering fields. In this context, glycerol and water can be used as plasticizers to make starches suitable for the thermoplastic process. In the thermoplastic process, the melting point and glass transition temperature of starches diminish owing to the heat and mechanical energy. With using fillers which are cellulose-based natural fibers, the durability of starches can be increased [9].

5 Biodegradability Testing

In industry, laboratory testing methods are utilized to determine biodegradability, a crucial factor for the evaluation of the eco-friendly behavior of substances. Biodegradability is an important parameter because a biodegradable substance will lead to no longer risk in the environment.

Biodegradation test of plastics: In order to determine of biodegradation of plastics, ISO 14852 method is utilized. The ISO 14852 method is a plastics-specific method used to determine the aerobic biological grade in an aqueous matrix by measuring CO₂, ISO 14852 analysis typically takes between 6 months and 28 days and compares the biodegradability of the test sample against the control samples.

Soil Burial Test: The soil burial test is used to determine the biodegradation of textile fibers. According to the burial method AATCC 30–1993, natural soil is used to fill the pot to a depth of 11 cm. The prepared samples are first weighed, buried 3 cm from the bottom, and allowed to reduce for 28 days after the weight of the samples was measured.

6 Bast Fiber-Based Bio-Composites

Composite material, which has recently introduced itself to the world in a short time, has become indispensable in many daily areas such as space-air systems, automotive, and sports. Generally, composite materials, although they can be designed in various forms, are mostly formed by the reinforcement of glass, carbon, aramid, or ultra-high molecular weight polyethylene (UHMWPE) fibers to a polymer matrix such as epoxy, polypropylene, polyethylene, etc. In addition to the advantage of increasing the use of composite materials, the wastes consumed for the material to be formed create a problem. Furthermore, recycling composite materials is hard because of forming two materials which are fiber and matrix. Disposal and usage of these composites occur environmental problems. Furthermore, sustainability and cost of traditional

composite raw materials may be a problem in the future. In order to reduce environmental problems, a variety of attempts have been carried out to use biodegradable polymers in the composites as reinforcement. These disadvantages cause to production of bio-composites. Environmental studies that promote themselves as green composites also focus on the composite material being made from renewable resources. The common usage areas of bio-composites are the construction, automotive, furniture, and packing industries. In the manufacturing of bio-composites, bio-fibers (generally cellulose-based fibers) and bio-matrix are used. Bio-composite materials can be produced with different techniques which are hand lay-up, spray-up, filament winding, resin injection, and pultrusion [21].

Hand Lay-Up Method: The matrix is impregnated on the fiber layers by manually laying them on a mold with reinforcing fabrics prepared in woven or broken form. Before the fiber is put into the mold, the mold surface is cleaned. The matrix is applied to the material at the final stage, where it is important that the matrix penetrates into the fibers optimally [21].

Spray-Up Method: This method is the manual laying method with mechanical parts. The fibers are mixed with resin by a hardener. Due to the roughness that may occur on the surface after spraying, the surface is prepared by smoothing it with the help of a roller [21].

Fiber Winding Method: The fiber winding method is used for mass production of products with a special shape. In this method, fibers are continuously heated with resin and pulled out of the reel. With the increase of the wrapped fiber layers, the product hardens and the rotating mold is separated from the product. Materials such as tanks and pipes with circular geometry are generally produced with this method [21].

Resin Injection Method: In this method, a two-piece mold is used. Felt, fabric, and both of these are used as reinforcement elements. The reinforcement material is placed in the mold in such a way that it fills the mold and is closed. It is coated with late-dissolving resins in the matrix to prevent the fibers from being dragged into the mold. Matrix injection can be applied in cold containers, warm or up to 80°. Due to the closed mold, harmful gases are reduced. This method is used in the manufacture of complex parts [21].

Pultrusion Method: Pultrusion process continuous constant section composite profile. It is a low-cost mass production method in which the products are produced. The reinforcement material is introduced into the resin bath before the forming mold is heated up to 120–150°. In this method, the orientation of the fibers affects the strength of the material [21].

The increasing number of studies have been performed on the growing significance of the new bio-composites. Some of these studies were summarized in Table 2.

Table 2 Properties of some bast fiber-based bio-composites are investigated in the literature

| Fiber | Bio-based matrix | Properties investigated | Reference |
|------------------|------------------------------------|--|-----------|
| Pineapple leaf | Polycarbonate | – Mechanical behaviors – Thermal stability | [22] |
| Ramie | Poly lactic acid/poly caprolactone | – Tensile and impact strength | [23] |
| Coir | Natural rubber | – Tensile strength | [24] |
| Bamboo | Natural rubber | – Tensile strength | [25] |
| Flax | Poly(lactic acid) | – The interfacial characterization | [26] |
| Kenaf | Poly lactic acid | – Tensile strength – Storage modules | [27] |
| Kenaf | Poly-L-lactide | – Storage module – Thermal stability – Crystallinity | [28] |
| Hemp | Poly lactic acid | – Glass transition temperature – Melting point – Mechanical behaviors – Thermal stability | [29] |
| Short flax fiber | Poly(ϵ -caprolactone) | – Mechanical behaviors – Crystallinity | [30] |
| Flax | Poly(ϵ -caprolactone) | – Crystallinity – Tensile strength – Storage module | [31] |
| Jute | Polybutylene succinate | – Weight loss – Biodegradability | [32] |
| Hemp and kenaf | Cashew nut shell | – Tensile properties – Porosity – Fracture surface | [33] |

7 Biodegradability

Biodegradability is described as the decomposition ability of material after interactivity with biological micro-organisms. Biodegradable material refers to a substance that can be converted into basic substances such as CO_2 and water after being biodegraded with the help of micro-organisms in nature and participate in the cycle in nature. Due to biodegradation, time limit and compostability are not required. Biodegradation occurs after the biological interaction in the biological environment and can be classified as enzymatic and hydrolytic biodegradation. In enzymatic degradation, an enzyme is required actively for degradation. Enzyme includes a specific functional group that can interact with a biodegradable polymer chain. Most of the biodegradable polymers contain unstable, easily hydrolysable functional groups such as amin and ester. When the biodegradable substrates are placed in a physiological environment, water diffuses into this polymer matrix and hydrolyses polymer chains to break them down. Biodegradation of products is removed from the matrix surface

with diffusion. Some properties such as water permeability and unstable hydrolytic bonds fundamentally determine the rate of hydrolytic degradation and surface erosion occurs. When the rate of water penetration into the polymer is greater than the rate of water diffusion, the polymer is deteriorated by surface erosion. The biodegradation of polymers by hydrolysis can be catalyzed using acids, bases, and enzymes [34].

A variety of factors affect biodegradation, and these factors can be organized below;

Hydrophilicity: Hydrophilicity can be identified as the attraction to water, while repellent of water is assigned as hydrophobic. Hydrophilic molecules are known as polar molecules [35].

Chemical structure: Chemical structure is defined as the arrangement of atoms in a molecule (in a radical or ion with atoms) and the chemical bonds. The structure theory was developed in about 1860s because of the determination of the chemical structure of the benzene derivatives. In order to determine the chemical structure of any substituent, the constitution and empirical chemical composition of the molecule can be known.

Hydrolysis mechanism: Hydrolysis of a substance commonly occurs in the environment. Hydrolysis is a significant reaction in the ground, surface, fog, and porewaters. Frequently, the hydrolysis mechanism occurs in two types which are nucleophilic substitution and addition–elimination. In nucleophilic substitution commonly takes place in epoxides and phosphate esters. Addition–Elimination frequently takes place when the leaving group is connected to sp^2 hybridized acyl carbon group, such as with carboxylic acid derivatives consisting of anhydrides, esters, amides, urease, and carbamates.

Glass transition temperature: Glass transition temperature is defined as the temperature that the carbon chains start to move. At the glass transition temperature, the amorphous regions experience the transition from a rigid state to a more flexible state making the temperature at the border of the solid-state to rubbery state. It is believed that the gap between the molecular chains rises by 2.5 times at this temperature [36].

Molecular weight: The molecular weight is defined as the mass of a molecule. Distinctive molecules of the same substance may have different molecular weight since they consist of different isotopes of an element. Molecular weight is calculated from the atomic weight of each molecule.

Environmental condition: Environmental conditions affect the biodegradability of substances. Most substances are affected by the moisture and temperature of the environment. Especially, the substance having hydrophilic groups tends to absorb moisture compared with the substance without hydrophilic groups. The biodegradation of these substances enhances with the increase in moisture of the environment.

Porosity: Porosity is defined as the ratio of the total volume of the material to the total pore volume in the material. The porosity of a material can be calculated with this equation;

$$h = \frac{V_p}{V}$$

where h is the porosity, V_p is the total volume, and V is the total pore volume of material. The increase in the amount of porosity represents the increase in the air of material [37].

8 Hydrolytic and Enzymatic Biodegradation

Biodegradation mechanism occurs via abiotic (such as photodegradation, simple hydrolysis) or biological (such as enzymes) sources. Hydrolytic biodegradation is defined as the forming of oligomers and monomers resulting in the chemical bonds in the polymer main chain combining with water. Hydrolysis reaction materializes with acids, alkalis, and enzymes. After the biomaterial is placed in the degradation environment, it absorbs water and swells, and biodegradation proceeds from the outer surface of the material to the inner surface. Hydrophilic or hydrophobic character of polymer affects the degradation. The susceptibility of the polymer to hydrolysis follows; (i) hydrophilicity of hydrolysable bonds, (ii) hydrophobicity of hydrolysable bonds, (iii) hydrophilicity of non-hydrolysable bonds, and (iv) hydrophobicity of non-hydrolysable bonds. Biodegradable polymers which are esters, glycosides, orthoesters, anhydrides, amines, urethanes, and urea involve hydrolysable bonds. Polymers with strong covalent bonds in the main chain (such as C–C bonds) and without hydrolysable groups require a very long time to degrade. Polyesters, polycarbonates, polyanhydrides, polyurethanes, polyorthoesters are some of the polymers subject to hydrolytic degradation. Different types of hydrolysis mechanisms have been investigated and it was obtained that it is hydrolysed in the main chain as well as in the stalactite groups. With enzymes, the degradation occurs from the substance surface to the inside. Enzymes are biological catalysts that accelerate the rate of reaction in living organisms without undergoing any permanent changes. Without enzymes, a variety of reactions in cellular metabolism does not become. Hydrolysis reactions can be catalysed with many enzymes which are protease, esterase, glycosidase, and phosphatase. In this context, some of these enzymes are expected to play an important role in the biodegradation of biomaterials by catalysing hydrolysis reactions. For example, the degree of biodegradation of polyurethane was observed to be approximately 10 times faster in the presence of cholesterol esterase enzyme than in phosphate buffer solution [38].

9 Conclusion

The current generation has focused on environmental preservation because of the increasing environmental concern. Furthermore, a variety of investigations have been carried out with the use of natural fibers in enhancing thermoplastics and thermoset composites in order to develop their mechanical behaviors. Recently, natural fibers especially bast fibers drawn attention as an alternative to synthetic fibers owing to having many properties which are low density, high specific strength, high stiffness, low cost, biodegradable, sustainable, and ecological.

Composite materials are defined as the combination of two or more different materials to manufacture a new engineered material. The mechanical behaviors of composites depend on the ratio of reinforcement, the interfacial adhesion between reinforcement and matrix, the mechanical behaviors of matrix and reinforcement, the surface modification of fibers, the fiber orientation and dimension, test condition, and volume fraction. Crucial progress has been achieved in the advance of biodegradable composites which are like conventional products. Availability, low cost, and biodegradability gains many advantages to these composites. Biodegradable composites are in a world of depleting resources. With the increasing climate crisis, the demand for recyclable materials will increase even more and it is deemed that biodegradable composites will be here to stay. In the present day, bast fibers are frequently used in the production of biodegradable composites. Because of climate change, researchers and industry may focus on discovering novel plant-based fibers to reinforce polymer composites.

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