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Biotechnology on Biopolymer in Automotive Interiors

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Abstract—Biopolymers are renewable resource-derived polymers that attract interest as environmentally sustainable resins, since they are manufactured without relying on fossil fuel energy. The application of polylactic acid (PLA) and other biopolymers in the automotive sector (especially indoors) needs the products to meet the quality requirements such as high strength, low level of sunlight disruption, abrasion resistance, high longevity and high fire resistance. Owing to the fact that injection molding produces products with high dimensional tolerances at short cycle times and results in lower costs, hence the production techniques of polymer is crucial. In recent years biofibre-reinforced PLA composites have been of considerable concern. By combining a biodegradable matrix with biofibre reinforcement a biocomposite, a completely biodegradable material, is literally feasible. We may also look forward to ambitious R&D in the production of materials that are bio-degradable over those manufactured from polyester as its reprocessing which prove costlier than the disposal and composting of items such as seats manufactured from PLA fabrics.

Keywords—biopolymers, PLA, automotive, injection molding, biofibre-reinforced, biodegradable

3.1 Introduction

A. Biopolymers

Industrial biotechnology can be defined as the use of modern biological life sciences in various industries. Biotechnology has a myriad of applications in our day to day life such as with simple processes such as the brewing of beer, use of enzymes in detergents, production of fermented food, production of antibiotics, nutritional supplements etc. It also includes processes (production of biofuels, treatment of effluents) that contribute to creating efficient, eco-friendly environments.

Biopolymers are polymers derived from renewable resources such as cellulose and starch draw attention as environment-friendly resins because they are produced without relying on fossil fuel resources. In addition, the plants which provide the raw materials for these polymers absorb carbon dioxide as they grow, while the polymers themselves emit smaller quantities of CO2 when they are disposed of with an incinerator. The polymers that are based on renewable raw materials, as well as the polymers that are produced by biological routes, are generally biodegradable. The bio-based polymers, however, do not necessarily need to be biodegradable. This means that polymers that contribute to the protection of the environment also include the bio-based polymers that are not biodegradable and vice versa. For this reason, the terms “environmental polymer,” “enviropolymer,” and “biopolymer” were coined for the sake of convenience in order to give a generic name to the bio-based polymers that are not biodegradable, and to the biodegradable polymers (including fossil fuel-based and bio-based polymers.

The main property that distinguishes biopolymers from fossil fuel-derived polymers is their sustainability, especially when combined with biodegradability. Biodegradable biopolymers from renewable resources have been synthesized to provide alternatives to fossil fuel-based polymers. They are often synthesized from starch, sugar, natural fibers, or other organic biodegradable components in varying compositions. The biopolymers are degraded by exposure to bacteria in soil, compost, or marine sediment. When the biodegradable biopolymers are subjected to waste disposal by utilizing their characteristic of being degradable by the bacteria in the ground, it significantly reduces emission of CO2 compared with conventional incineration. Therefore, attention is drawn to the use of biodegradable biopolymers from the viewpoint of global warming prevention. In recent years, with the critical situation of the global environment worsening due to global warming, the construction of systems with sustainable use of materials has been accelerated from the viewpoint of effectively using limited carbon resources and conserving limited energy resources. The Kyoto protocol, together with the desire to reduce society's dependence on imported crude oil, has directed researchers' efforts toward the use of biomass as a source of energy and of commodity chemicals. Furthermore, the cost of petroleum feed stocks has risen dramatically and the demand for using "green" (or renewable resources) is increasing [1].

The application of PLA and other biopolymers in the automotive sector (especially interiors) requires the products to meet the quality standards of high degree of strength, low degree of damage from sunlight, resistance to abrasion, high durability and high resistance to fire. Although PLA has certain limitations to meet the standards, new materials and modifying agents are expanding both its reach and applications. Efforts are focused on boosting mechanical and thermal properties so biopolymers can be effective alternatives to less costly commodity materials. Among the new developments are PLA foam grades for thermoformed meat trays, new additives for greater strength and reduced degradation, and fiber-reinforced materials that will expand its uses multifold. Apparently, it is apt to say that the automotive industry is the perfect place for biopolymers like PLA to make a start as a globally marketed and widely applied as an eco-friendly product for automotive interiors besides other durables.

In this respect, Japanese auto companies like Mazda have been principal initiators in the field which is seriously considering using bio-based and renewable plastics for their auto interior parts. The commendable effort put behind reviewing renewable plastics as alternatives to the oil-based counterparts by such companies will certainly set the stage in order to promote considerable research and developmental activities to help realize an 'eco-friendly' automobile society.

Japan 's Mazda Motor Corp. launched the world's very first biofabric which were used in the seat covers and door trims. The biofabric which falls under the 'Mazda Biotechmaterial' brand name is made of 100% polylactic acid (PLA). The biofabric, jointly developed by Mazda with Teijin Limited and Teijin Fibers Limited at R&D facilities in Hiroshima, does not possess any oil-based materials yet it provides the quality and durability required for use in seat covers. A number of technologies were amassed to control the entire molecular architecture of raw resins to improve fiber strength until it qualified for the standards of strength, durability, abrasion resistance, lower degree of damage from sunlight, in addition to being flame retardant. Mazda's biofabric technology that contains 100% plant derived PLA will be a firm foundation for future bio-based materials to reduce the burden on the environment.

3.2 Biotechnology on Biopolymers in Automotive Interior

A. Polylactic Acid (PLA)

Polylactide or polylactic acid (PLA) is a linear aliphatic poly(a-ester) or a-hydroxyalkanoic acid derived polyester. PLA is obtainable primarily by the ionic polymerization of lactide, a ring closure of two lactic acid molecules. At temperatures between 140°C and 180°C and under the action of catalytic tin compounds (such as tin oxide), a ring-opening polymerization takes place. Lactide itself can be made through lactic acid fermentation from renewable resources such as starch by means of various bacteria. PLA can also be produced directly from lactic acid by polycondensation [1].

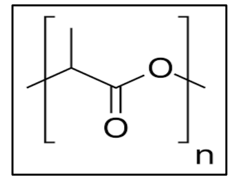

Figure 1: Polylactic Acid (PLA) [2]

The properties of PLA depend primarily on the molecular mass, the degree of crystallinity, and possibly the proportion of co-monomers. The material has water-repellent or hydrophobic behavior. PLA is soluble in many organic solvents, such as dichloromethane or the like. PLA has higher transparency than other biodegradable polymers, and is superior in weather resistance and workability.

PLA has low melt viscosity, which is required for the shaping of a molding. PLA is, however, slow in the crystallization rate with long molding cycles and has poor gas properties; furthermore, it has inferior thermal resistance and mechanical characteristics (toughness, impact resistance, and the like) compared with those of existing synthetic resin molded articles. To solve these problems, many countermeasures are used in forming PLA, including blending PLA with other polymers, and compounding various kinds of substances as filler; thus, PLA products have been entering practical applications.

PLA is gaining a lot of interest due to its biodegradability, biocompatibility, and renewable resource based origin. It can be said that PLA is a low environment load polymer that does not cause a direct increase in the total amount of carbon dioxide gas, even if the polymer is finally biodegraded or burned up. The biodegradability of PLA, however, has both positive and negative aspects. The positive aspects of PLA are its ability to form non-hazardous products when PLA polymers or articles are discarded or composted after completing their useful life, and its slow degradation period (several weeks up to about one year), which is advantageous for some applications as it leads to a relatively good shelf life. PLA is the most common biopolymer currently on the market. As such, it has a variety of brand names associated with it.

Table 1: PLA technical data [3]

Melt temperature (°C)	188-210
Tensile strength at break (MPa)	48
Tensile elongation at break (%)	2.5
Density	1.24
MFI (190°C/2.16 kg) (g/600 s)	30-40

B. Biological Process (Injection Moulding)

Since injection molding provides products with high dimensional tolerances at short cycle-times and resulting lower costs, it is an important manufacturing process for polymers. Determining the correct setting for injection molding is a major concern in the plastics industry because the processing parameters have crucial effects on the quality of products. The filling time, melting temperature, molding temperature, and packing pressure are the parameters that govern the injection molding process [4].

The composite mechanical properties can be optimized through the variation of neat base materials PLA, PHA, and cellulosic fibers weight fraction ratio. In order to select the best cellulosic fibers weight fraction ratio, a mechanical characterization of the composites was realized.

The envisaged tensile and flexural properties were the initial modulus and the maximum/yield stress. The heat deflection temperature (HDT) was measured using the method HDT. A with an applied stress state of 1.8 MPa and an increasing temperature rate of 120 °C/h. All specimens were produced via injection molding technique by a compound injection molding machine in which it was possible to adjust the feed throat of each hopper to obtain the proper weight fraction ratio. The mold temperature was at 20°C in order to allow successful part demolding. A constant injection velocity of 20 mm/s (corresponding to an injection flow rate of 6.3 cm3/s) was maintained.

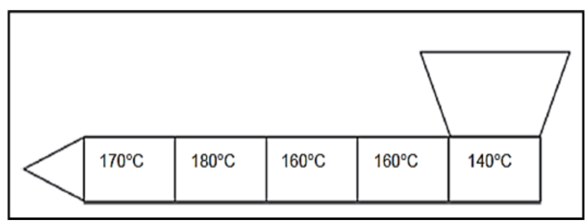

Figure 2: Injection spindle temperature profile of the injection machine [3]

As the interior door trims are mainly injection molded into ABS or PP copolymer, we compared the obtained results with general ABS and PP properties. Using the online databases of matweb.com, it was possible to assume the main properties of ABS and PP.

Table 2: ABS and PP general properties [3]

	ABS (injection grade)	PP (injection grade)
Tensile modulus [GPa	2.33	1.72
Maximum tensile stress [MPa]	38.4	31.3
Maximum flexural stress [MPa]	68.6	48.1
Absorbed energy [J]	22.7	10.8
Heat deflection temperature [°C]	96	63

After verifying that the cellulosic composite is suitable for an interior automotive application, a cabin light support part from a 2008 model of a well-known OEM was produced from this composite. The original part was produced in an ABS blend by injection molding. The aim was to verify if the injection molding process would be suitable for cellulosic fiber composite part production. It is worth mentioning that the mold used produced the original parts by ABS, whereby the mold parts produced will not be optimized for our green composite. It is possible that the thickness of the part can be adjusted and, therefore, the weight of the part can be reduced. This new composite will be produced by repeating a similar injection process used for interior automotive applications, namely the neat polymers PLA and PHA, which will both be shipped from the supplier in a pelletized form. During the injection process, the fibers will be added to the mix. The process used is compound injection molding (CIM), in which all materials are directly inserted into the fuse. The CIM machines ensure that all materials are well mixed into the fuse. In the first stage, the two polymers are mixed, and in the following stage, the cellulose fibers are added to the blend in the right ratio and at the proper time, driving a homogeneous dispersion of all materials in the fuse. The final stage is the injection into the mold. At this time, the polymer blend is perfectly mixed and the reinforced is well dispersed.

As one may notice, no distortion or visible injection molding defects are present. In that sense, this indication would potentially allow the replacement of the current part with parts made of cellulosic composites. Consequently, this will allow the incorporation of the systems and parts that are integrated into the cabin interior light part and other interior parts.

3.3 Advantages of PLA Biopolymer

A. Achieve Cheaper Price when Blending with PLA

The major problem identified with wood fibers (cellulose derived from trees) and natural vegetal fibers to reinforced polymer composite materials is the incompatibility between the hydrophilic character of the natural fibers and the hydrophilic thermoplastic matrices during incorporation, which leads to undesirable properties of the resulting composites. It is, therefore, necessary to alleviate this problem by various fiber polymer interface modifications to improve the adhesion between fiber and matrix, which results in an improvement of performance of the resulting composite. The most critical application sectors for these biocomposites are construction (decking and siding) and automotive interior parts. Between 10% and 15% of the total European composite market is covered by wood-plastic composites (WPC) and natural fiber composites (NFC).

One possibility is the use of interior door trims of biodegradable polymers from renewable sources such as polylactic acid (PLA) and polyhydroxyalcanoate(PHA) instead of traditional petrol source polymer such as polypropylene (PP), polyethylene (PE), or Acrylonitrile butadiene styrene (ABS). Among the biodegradable polymers from natural sources, PHA is the one that has the best properties and is expected to be able to fulfill these requirements. However, due to its current price, the solution is not economically viable. To make the eco-solution competitive, it is necessary to reduce the price of the final polymer. One way to accomplish this is to blend it with cheaper polymers, such as PLA [3].

Bio-fiber-reinforced PLA composites have been of great interest in recent years. Through mixing a biodegradable matrix with biofiber reinforcement, it is practically possible to create a biocomposite, a fully biodegradable material. Work on bio-fiber-based PLA composites has reported certain benefits such as strong processability, high-specific resilience, compostability, high durability, renewability, and recyclability [5].

Current objectives of the automotive industry are to reduce fuel consumption and CO2 emission. One way to accomplish this is to reduce vehicle mass. This offers an opportunity to expand biobased and biodegradable polymer applications suitable for automobile construction. Biodegradable polyesters can be used in automotive manufactures as coatings for interiors or exteriors, thermoplastic elastomers, fiber reinforced thermosetting, shape memory and self-healing items, piezo resistive components for interior trims prototypes and for strain gauges for vibration monitoring. One of the most commonly used materials is composites. Those materials have good mechanical properties and their lative facility of combining them with other materials. In the automotive industry, biobased polymer composites, butonly those that can be recycled, could be used instructural parts of the vehicle's body such as door handles, dashboard fascia, panels, floor trim, scooter frames, secondary paneling for interiors and under bonet. About 50% of all interior components, including safety subsystems, door and seat assemblies in commercial vehicles are made of plastics. Starch-based polymers are used as an additive in the manufacturing of tires. Starch reduces the resistance to the movement, the consumption of fuel, and reduces fine greenhouse gas emissions. Industrial sectors, such as construction, automotive and transportation sectors including aviation and aerospace use additive manufacturing as an integral tool in the design process. Three-dimensional (3D) printing technology allows us to build concept cars and aircraft, but it also allows for the rapid printing of components using experimental material and compares them with traditionally made parts [7].

B. Completely Biodegradable

These sustainable composites will use 100% renewable source materials, while meeting current applicable crashworthiness standards and aesthetic requirements [3]. Since petroleum-based plastic products generally do not degrade in a landfill or composting environments, they pose a serious environmental problem. For this reason, biodegradable polymers such as PLA have been the subject of many studies during the past decade. Moreover, PLA is also being synthesized from corn, which is a renewable plant feedstock. The Nebraska facility of Cargill Dow is capable of producing up to 300 million pounds (140 000 tones) of PLA per year, using 40 000 bushels of corn per day (1 088 640 kg) 41 and production is expected to more than triple to one billion (0.45 billion kg) pounds by 2007.42 The adoption of PLA for automotive parts has also been studied since PLA-based automotive parts emit less CO2 than petroleum-based thermoplastics.

C. Improves Mechanical Properties

Most research on PLA composite ultimately seeks to improve the mechanical properties to a level that satisfies a particular application. Indeed, some researchers consider the enhanced toughness the main advantage of natural fibers in composites. One way to improve the mechanical and thermal properties of PLA-based bio-polymers is to modify them by adding fillers or reinforcements [4].

Because of outstanding mechanical properties and biodegradability, PLA-based composites have attained great commercial interest in the composite industry among the biopolymers. The fibers used in PLA composites as fillers have improved mechanical properties for completely natural materials. The factors considered in mechanical characterization are fiber volume/weight fraction, fiber layer stacking sequence, processing methods, fiber treatment and environmental effects. Bio-fibers such as hemp ramie, kenaf, rice straw, abaca, wood, coir, jute, sisal, bamboo, rice husk, oil palm, and flax were used to reinforce PLA.

Studies have attempted to boost PLA's impact power by combining with soft polymer by incorporating plasticizer and impact additive, etc. The reports showed that the above techniques significantly improved PLA's toughness at the cost of stiffness. In view of this, there has been considerable interest in the development of compatibilizing graft copolymer in recent years to provide better compatibility between PLA and fiber together with good impact strength. Synthesized a poly (lactic acid)-graft-glycidyl methacrylate (PLA-g-GMA) graft copolymer and used it as a consistency in biocomposite PLA/bamboo flour. GMA's graft copolymer was used in composites as a suitable substance since GMA is a biofunctional monomer composed of an acrylic group at one end and an epoxy group at the other end. GMA's epoxy group can react with PLA's fiber or carboxy group of hydroxyl while the acrylic group undergoes polymer chain coupling to form a stable chemical bond between PLA matrix and fiber. PLA-graft-GMA's compatibilizing effect on the efficiency of PLA/bamboo flour biocomposites and observed improvements in mechanical properties and thermal stability after the introduction of compatibilizer [5].

D. Processed at Low Temperature

PLA can be melt-processed with standard processing equipment at temperatures below those at which natural fibers begin to degrade, and at a relatively low cost. Hence, PLA is a versatile material with applications in the automotive industries [4]. Bio-fiber composites are recognized to provide good, low density, low-cost, non-abrasive materials for manufacturing. From the processing point of view, it is very important to know the thermal activity of mixtures dependent on fiber materials and polymers [5].

Table 3: Thermal characterization of PLA/Bio-fiber composites [6]

Composites	Fiber (%)	Characterizati
PLA/oil palm MCC	1, 3, 5	TGA
PLA/kenaf, PLA/rice husk	20	TGA
PLA/ramie	30	DMA, DSC, TG
PLA/RSF	7, 8, 9	DSC, TGA
PLA/bamboo fabric	51	TGA
PLA/coir	5–30	DSC, TGA
PLA/kenaf/thymol	40, 10	TGA
PLA/banana fiber	10, 20, 30, 40	DSC, TGA
PLA/Bamboo fiber/wood fibers/Coir fibers	10	DMA, DSC

3.4 Effect of PLA Biopolymer on Today Society

Due to its unique characteristics, including strong clarity, shiny look and high rigidity, PLA has the potential to replace conventional polymers such as PET. It is necessary to transform polylactic acid into fiber and film. While PLA has been used in the packaging, automotive and construction industries, due to low glass transition temperature, it is still not suitable in electronic devices. PLA's glass transition temperature ranges from 55 to 56°C whereas the melting temperature ranges from 150 to 175°C. PLA has mechanical properties similar to or superior to conventional polymers. Low toughness and high cost of production, however, are PLA's major drawbacks. Extensive research has been reported to reinforce natural fillers with PLA matrix to overcome these disadvantages.

In the field of polymer composites, the development of biodegradable polymers based biocomposite reinforced with biofibers opens up a new area. Biocomposite properties depend on the type of fiber, percentage of fiber content, interfacial adhesion between matrix and fibre, surface fiber alteration and application of additives such as nanofiller, binding agent, compatibilizer, etc. In addition, owing to the stiffening impact of fiber, the integration of lingo cellulosic fiber into biodegradable polymers results in a significant improvement in tensile modulus. A research utilized wood flour as a polypropylene reinforcing. Fabricated wood flour-enhanced PLA-based biocomposites. They reported higher modulus of biocomposites compared to virgin PLA. The mechanical and thermal properties of PLA with rice straw fiber changed with butyl acrylate monomer were examined in another study. We also documented enhancing the mechanical properties of polymeric materials by introducing fiber [5].

Further down the line, we can expect the automobile companies to impose certain obligations for the supply chain to provide products that are environmentally friendly. In addition, we can also look forward to an aggressive R&D in development of materials which are bio-degradable over those made from polyester as its reprocessing may prove to be more expensive than the disposal and composting of products such as seats made with PLA fabrics. Another driving factor is the reduced dependence on petroleum. Also, for the PLA composting concept to be valid, other interior components such as foam, carpet, acoustic underlay and door panels might also need to be PLA (or any other compostable biodegradable plastic) in order to prevent the need at the end of the vehicle's life to separate biodegradable products from recyclable products. Considering the time it has taken PET to become prevalent, bio-based polymers is a concept that might even take half a century to be realized. Having said that, a journey to a thousand miles starts with a single step and thus, the application of PLA and other bio-based polymers in auto interiors is just a step towards taking the automotive sector towards sustainability [1].

Bio-fiber composites are commonly used globally in a wide range of applications such as packaging, medical, upholstery, textile and automotive interiors, etc. Mercedes-Benz E-class is a rich use of plant fibers. Using bio-fibers or filler materials is the easiest and most environmentally friendly way to improve the mechanical and thermal properties of PLA. These bio-fiber-based bio-polymers are used to develop various automotive components, such as dashboards, door panels, package trays, headliners and some interior components [5].

A. Automotive and Transportation Sectors Including Aerospace Applications

Current objectives of the automotive industry are to reduce fuel consumption and CO2 emission. One way to accomplish this is to reduce vehicle mass. This offers an opportunity to expand biobased and biodegradable polymer applications suitable for automobile construction. Biodegradable polyesters can be used in automotive manufactures as coatings for interiors or exteriors, thermoplastic elastomers, fiber reinforced thermosetting, shape memory and self-healing items, piezo resistive components for interior trims prototypes and for strain gauges for vibration monitoring. One of the most commonly used materials is composites. Those materials have good mechanical properties and their lative facility of combining them with other materials. In the automotive industry, biobased polymer composites, butonly those that can be recycled, could be used instructural parts of the vehicle's body such as door handles, dashboard fascia, panels, floor trim, scooter frames, secondary paneling for interiors and under bonet. About 50 % of all interior components, including safety subsystems, door and seat assemblies in commercial vehicles are made of plastics. Starch-based polymers are used as an additive in the manufacturing of tires. Starch reduces the resistance to the movement, the consumption of fuel, and reduces fine greenhouse gas emissions. Industrial sectors, such as construction, automotive and transportation sectors including aviation and aerospace use additive manufacturing as an integral tool in the design process. Three-dimensional (3D) printing technology allows us to build concept cars and aircraft, but it also allows for the rapid printing of components using experimental material and compares them with traditionally made parts [7].

B. Packaging Sector and Food-Services Sector Applications

Delivery of food products to the point of sale or to the consumer requires a large and varied amount of packaging product, each designed to serve its unique purpose. The function of packaging is three fold: the material from which it is made must be approved for direct contact with food, the design of packaging must protect its contents from external contamination, and also must serve to protect it from loss of flavor. Additional requirements address transportation and storage requirements. Starch is readily available in large volumes and at relatively low cost. It also has attractive physical properties, low permeability of gases and water (barrier), transparency or ability to impart desired color (optical), which makes it one of the best candidates for biodegradable food packaging. Thermoplastic starch is used for food wrappings and cups, plates and other food containers. Because starch has poor mechanical properties and poor resistance moisture which place limits on its uses this polymer can be blended with various polymers such as PLA, PCL or PVA. The polymer/starch blend can be used in the production of flexible and rigid films, allowing for thermoforming into rigid injection molded packaging trays and for coating of paper and cardboard (direct contact with food). Another polymer used for packaging material is cellulose and its derivatives, like cellulose acetate. It is extensively used in the packaging of fresh products and baked goods. Chitosan can be blended with PCL, protein such as zein, gluten, soy protein or whey protein. PLA is a proper candidate as green food packaging material, due to its high molar mass, easy processing by thermo-forming, and biodegradability. PLA is finding practical application in the production of beverage bottles, transparent rigid containers, bags (also from PBAT), jars, food containers, disposable cups, coating for all types of packaging and film packaging foams. Materials based on PLA and PHBV have shown effective application for the production of thermoformed containers for food packaging. PHAs such as PHB and its copolymers: PHBV, poly (hydroxybutyrate-co-hydroxyhexanoate) (PHBHx), poly (hydroxybutyrate-co-hydroxyoctanoate) (PHBO), poly (hydroxybutyrate-co-hydroxyoctadecanoate) (PHBOd) and P3HB4HB can be used in packaging for deep drawing foods such as bottles, disposable cups, laminated foils and fast food [7].

C. Agriculture and Horticulture Applications

Recent trends in agricultural application include the use of natural and synthetic biodegradable polymers such as agar, starch, pectins, alginates, chitin, lignin, cellulose and its derivatives, PLA and PCL to replace traditional plastics. Soil retention sheeting, agricultural foils, seed or fertilizer tapes and binding materials, threads, clips, stales, bags containing fertilizer, envelopes of ensilage and trays of seeds, plant pots are being replaced by biodegradable equivalents and disposable items so that the used biodegradable materials does not have to be removed after use. Natural polymers along with synthetic biodegradable polymers such as PLA or PCL can be used as carriers in controlled release systems of pesticides, herbicides, nutrients, fertilizers, pheromones to repel insects. The active agent can either be dissolved, dispersed or encapsulated by the polymer matrix or coating, or is a part of the macro molecular backbone or pendant side chain. PBAT can be used as greenhouse tunnels and mulching foils [7].

D. Medical, Pharmaceutical and the Dental Sector Applications

The fact that (bio) degradable polymers are readily absorbed by the human body drives both the scope of application and the extent to which they are used in medicine and dentistry. Some of the examples of their usage include assorted medical and dental devices or their components, surgical sutures, (bio) degradable components used in the repair of ligaments. These polymers also found a wide application in the manufacturing of tools used during a variety of surgical procedures as well as for the making of devices that are permanently implanted. The accessibility of coated or time-released drugs requires the availability of carefully chosen and formulated polymers that will allow for a uniform release of predetermined doses of medication overtime. (Bio) degradable polymers, such as PGA, PLA, poly (glycolide-co-lactide) (PLGA), poly(p-dioxanone), poly(glycolide-co-trimethylene carbonate) and PCL are used as materials for surgicals uterus or resorbable implants, stiffening dressings and controlled drug delivery systems. In dental procedures, the (bio) degradable polymers are used as void filler following tooth extraction (porous polymer particles can be packed into the cavity to promote quicker healing) and a (bio) degradable film that can be positioned to prevent epithelial migration following periodontal surgery. There is an expanding need in the field of orthopedics for joint replacements, items used in their pair of fractures, bone fillers and bone cement, as well as artificial orthopedic constructs used to replace parts that sustained irreparable damage. PGA, PLA and its copolymers, PHA and PCL are particularly desirable for orthopedic devices due to their excellent biocompatibility and the possibilities to adjust physical properties and degradation properties to a specific application. Implants are being developed using biopolymers such as collagen, elastin, hyaluronic acid, chitosan, silk, and starch. The synthetic and natural polymers have been combined with nano hydroxyapatite (nano-HAP) or tricalcium phosphate (TCP) which allows for the design of implants that have bone-like compositions. Another application of these polymers is the production of composites that simulates bone tissue growth. (Bio) degradable polyesters can also be used as a coating on a medical device or as completely biodegradable devices such as anastomosis ring and tissue staples, ligating clips, tissue engineering scaffolds, vascular graft sands tents [7].

E. Building and Construction Sector Applications

Unlike the automotive industry, the building construction is striving to reduce its CO2 footprint and emissions. Ecofriendly buildings are intended to provide a healthier place to live and work. Such materials include laminated wood plastic components, polymer compositions (polyesters with jute fibers or fiber-reinforced polymers). Biobased and/or biodegradable plastics can be used as molds for truss joints, high thermal insulation rigid foams, new mortars or concrete, piezo resistive strain gauges for monitoring mechanical deformations of structures. PLA-based composites could be used as internal window profiles or, with the addition of aluminum hypophosphite, can provide flame retarding properties to some construction materials. The application of the composites determines their classification: structural (bridges, and roof components), and non-structural (windows, exterior components, composite panes, door frames).

F. Consumer Goods Applications

This category includes a very large number of items ranging from domestic implement store creational sports items, toys, and consumables. A new generation of adhesives, paints, engine lubricants, and construction materials, as well as golf tee and fishing hooks, is made of biodegradable polymer materials. Toothbrush handles and adhesive tape backing include chemically modified plant cellulose. Traditional materials used in the manufacturing of coffee capsules, which are used in large numbers, are replaced with starch-based materials, or with biodegradable polyesters. A biodegradable material used in 3D printing made from non-genetically modified maize corn starch is used to produce clothes using a 3D printing method. Additionally, testing is underway to use it in the manufacture of toys. Cups, plates, bowls and shoes can also be made using this material. Biodegradable material from a marine shell is used to make Legoblocks, plastic balls, model toys, pens and art knives.

G. Electric and Electronic Sector Application

Composites based on hollow keratin fibers and chemically modified soybean oil find applications in electronics as new low dielectric constant material. Other electronic devices that use biodegradable polymer-based materials include capacitors, communication devices, loud speakers with advanced functionalities and paper-based displays made from wood lingo cellulose microfibers-based polymers or batteries for micro electromechanical systems. Electro conductive plastics were developed to manufacture electronics from sustainable sources. This is accomplished by spinning of different nano fibers individually or by hybridizing with other materials and incorporating them with suitable biobased polymers which can produce nano composites as possible superior structural components (lighter than their micro counterparts). These materials find application in a variety of electrical, optical and biomedical items such as components of various functional devices. Ecofriendly materials can be used in vacuum cleaners, as housing for power tools, and for portable electronic equipment including cellular phones. Electronic industry is also using biodegradable materials such as PLA composites. PLA can also be functionalized with various additives. PLA and kenaf are used as composites in electronic applications such as compact disks or computer cases. PLA can be enhanced by special technology to achieve properties such as conductivity, significant improvement in thermal stability or mechanical properties and are suitable for 3D printing technology, giving almost unlimited possibilities in the production of ready-to-use biodegradable polymer-based electronic materials [7].

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