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BIOPRODUCTS OF AUTOMOTIVE ACCESSORIES: RETHINKING DESIGN MATERIALS THROUGH CORNSTARCH, SUGARCANE AND HEMP

Apisak Sindhuphak*

Department of Architectural Education, Faculty of Industrial Education
King Mongkut's Institute of Technology Ladkrabang,
Chalongkrung Road, Ladkrabang District, Bangkok 10520, Thailand

ABSTRACT

Current *bioproducts* or *bio-based* products do not only require less energy to produce than petroleum-based products, they are made with renewable sources that engineered from excessive waste and natural local materials. This paper identifies alternative design solutions by suggesting a use of natural materials such as cornstarch, sugarcanes and hemp in designing automotive accessories. Leading automotive industries have focused on using bio-based materials for possible vehicle details such as dashboard panels, finishing trims and optional features and casing for light covers. A fermentation broth derived from cornstarch and sugarcanes, which were recovered as Polylactic acid or Polylactide (PLA), were selected by designer and automotive engineer to reconstruct bio-based materials to improve identity of bio-based design for an automotive world. This choice of material process yields similar quality to materials made from thermoplastic or materials categorized as lightweight-metal. Additional design examples of bio-based materials are products made from hemp fiber for bus seat in Canada, and biodegradable phone casing from England and Japan. These examples are described as solutions, which show sustainable use of alternative materials and suggest design applications that reflect concerns for the environment. The environmental benefits of bio-based products have produced biodegradable solutions instead of accumulating to the landfill at the end of their useful life. Expressing this environmental concern, this paper also attempts to display a possible design solution, where the design example of hemp bus seating and biodegradable phone casing are used as exemplar case studies to develop design methodology and philosophy of contemporary *bioproducts* in automotive industry.

KEYWORDS: bioproducts, bio-based products, PLA, PHA, cornstarch, hemp, sugarcane

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*Corresponding author: Fax: 662-326-4499
E-mail: ksapisak@kmitl.ac.th

1. INTRODUCTION

The use of *bioproducts* or *bio-based* products have been applied in the food industries such as fruit juice bottles, containers, cups, disposable tableware, as well as its packages. Medical products have also received benefits from using biodegradable materials that are designed as disposable and easy to decompose equipments or tools. Through a bacterial fermentation process of corn or sugarcane. Lactic acid is produced and have been used to manufacture thermoplastic and aliphatic polyester, which maintained lower risk for use as food containers or disposable syringe [1]. Nonetheless, high production cost and also complicated methods that cause slow progress in the development of the *bio-based* manufactured facilities and its waste management plants has affected the industry responses toward the wider applications of biodegradable materials, especially in areas of non-food and non-medical products. From the production perspective and the concern for natural resources applied as renewable materials for architecture and design industries, a concern for wider application is raised in term of quantity production as well as the quality of design derived from bio-based materials. Automotive design industry is one of the area where this paper have placed a focus on an alternative design process and philosophy, for the industry to use biodegradable materials as a design approach and to develop further solutions for future vehicle design.

Automotive industry has shown increased interests in seeking wider applications of the *bio-based* materials, as environmental concern solutions shown as new design of engine with bio-based components and where the use of biofuel are gaining more demand in the industries [2], particularly from natural plants plastic such as Polylactide (PLA), Polyhydroxyalkanoate (PHA), and Poly-beta-hydroxybutyrate (PHB) where the physical properties can be processed as thermoplastic, polyethylene, and polypropylene, respectively. PLA yielded a transparent or crystalline finish even when the polymers are blended into layers. The materials are commercially made into fiber stocks (non-woven) as well as film sheets for transporting purposes [3]. PHA derived from fermenting sugar and corn oils by microbes can be processed into biodegradable materials such as fiber, film, molding processes, as well as water repellant and scratch resistant coatings. Although new to the idea of design variations, these materials show the qualities that can be adapted to the design of car exterior and interior solutions.

At present, biodegradable quality becomes compatible to production process for applications on biomedical products and petrochemical derived products. These include methods of sustainable design, which can be accomplished into design ideas with emphasis on the physical properties of these engineered materials. Design samples provided in the paper focused on the use of the material's biodegradable functions that are not only related to the food industries, but also in consumer products that can be applied to the design methods in automotive area. Applications in these areas offer designer, engineer, and scientist opportunities for broader selection of designed materials in addition to the common materials (plastic or synthetic fiber) that are heavily used because of the lower production cost.

Therefore, the selections of bio-based materials are determined from the material physical properties and the concern for its life cycle after use. Physical propertie of PLA, particularly of its translucency, the sample of cornstarch and sugar transformation to form PHA and PHB, and additional use of hemp (lower translucency) has become evident that when the industry determine the new alternative solution, the design should show environmentally attributes and contribution to design friendly vehicles for the automotive industries. Their properties and current applications are intended as goal for *bio-based* products in the automotive accessories to demonstrate design approach and solutions that show the least hazardous consequences to the environment.

2. ENGINEERED MATERIAL PROPERTIES

Developing properties of PLA, PHA, and PHB (PHBV) addressed the level commitment between manufacturing, and design processes. The main focus is on the physical properties of material such as temperature discrepancies, and product life expectancy have become the main concern for these design areas. The goal for this design direction is settled to create a biodegradable material for use in automotive industries, where it could lower the demand of high energy consumption, and could also lead the production process to reach structural validity as well as prolong a usage period according to the need and design solutions. The properties of selected research materials that demonstrated the integrity of well balance solution such as production of household products are used as example of design studies in this section.

Materials chosen for critical element in producing PLA are from natural plants and vegetations. The process saves oil and generates far less air pollution of CO_2 than average petrochem-based plastic. Among these plants, cornstarch and sugarcanes can be extracted and formulated into plastic that are biodegradable. PLA properties were conceived from the bonding between its physical properties and rigid plastic compound solution gathered from the organic materials reaction. Corn plastic extracted from cornstarch has been produced for 20 years, but the polymer was too expensive for broad commercial applications until 1989, when Patrick Gruber, a chemist looking for new ways to use corn, invented a way to make the polymer more efficiently. Teamed with his wife, he created his first prototype PLA products on his kitchen stove. In the beginning, it cost $200 to make a pound of PLA; now it is reduced to one dollar [4]. Currently, the physical blend of PLA can be used to widen the applications including woven shirts (iron ability), microwavable trays, hot-fill applications and even Acrylonitrile-Butadiene-Styrene (ABS) engineering plastics (where the material is blended with rubber-like polymer such as ABS). Even for improving form-stability, while maintaining transparency of low-end package application, the material has also earned an interest for commercial market. Through development of the material, possible application properties includes biodegradable capability, high clarity, high crystalline, food contact acceptable, high gloss, high grease resistant, heat resistance, high heat seal, good machinable, and oil resistant [3]. Nonetheless, based on its natural compound, PLA has had difficulties dealing with heat during moulding process and the period of usage, which has become a reluctant choice of material to further develop product or design parts that dealt with high temperature.

Dealing with high temperature, as the material would be applied in either organic or geometric form if intended for contemporary design solution, the melting temperature of PLA has been improved in order to support wider range of applications. The list of this specification number indicates higher melting temperature as the material has undergone treatment to maintain some qualities that match its predecessor materials like Polyethylene (PET) and possibly hold the strength of ABS. Current manufacturing processes and industrial properties of PLA are indicated in Table 1. These numbers derived from the production process, which produce the materials within ranges of material properties that are identified as material capabilities for use in industrial productions and design selections. The level of Rockwell Hardness gradation has also shown the increase in strength to match the properties of PP (Polyprepylene) or PET [3].

Table 1 Properties and Requirements of PLA [3]

Properties and Requirements of PLA	
Properties	**Requirements**
Specific Gravity	1.24 to 1.26
Mold Shrinkage, Flow (*cm/cm*)	0.0040
Melt Mass Flow Rate (*g/10 min*)	9.9 to 10
Flexural Modulus (*psi*)	537000 to 555000
Tensile Elongation (*%*)	2.5 to 100
Rockwell Hardness	84 to 115
Notched Izod Impact (*ft·lb/in*)	0.240 to 0.543
DTUL at 66 psi (0.45 MPa) (*°C*)	55
Mold Temperature (*°C*)	23.9 to 29.4

Furthermore, PLA pre-processed mold temperature is at the level between 23.9-29.4°C. These ranges required lower energy consumption compared to other synthetic plastics, which has higher level of molding preparation and process temperature. PHA and PHB hold similar production properties since the based compound are also generated from natural plant. Sugar industry has supported the development of PHA and PHB.

PHA was used on products such as water container, coffee cup, soup bowl, and hold a high non-aquatic resistant properties that also reflect ease of decomposition when dissolved in water [5]. It has physical properties resemble to polyolefins, which are associated with elastomeric LDPE, HDPE, and PP. From production with printable quality, this material could also yield the appearance similar to polyester, which made possible for screening color for production that required printing solution. Additional properties are also known as having quality that resists grease and oil, which makes the material attractive for manufacturing picnic plates and utensils. PHA also has a melting points ranging from 40 to 180°C, which places it to close characteristic of thermoplastic or elastomeric materials. In addition, the common type of PHAs is poly-beta-hydroxybutvrate (PHB), which has properties similar to PP and can also demonstrate characteristic as stiffer and tougher when arrange as copolymer known as polyhydroybutyrate (PHBV). This solution helps extend the use of PHA and PHB plastic for package design, for logistical export business, for products such as automobiles, or for large household appliances.

In such field of design, especially in package design and small household products, the use of PHA and PHB have contributed to more than 50% of regular consumption of every 300 lbs of polymer used for production of such products. In term of productions, PHA and PHB can be produced through injection molding, extrusion, thermoforming, blown molding, and also casting molding of film sheets. Figure 1 shows variation of products produced by using PHA and PHB through thermoforming that shows thickness of material between 15-50 mil-sheets and 2000-2500 MPa tensile modulus. The prototype of this design employed the vacuum forming processes to produce heat resistant coffee lids and cup and as well as a small condiment cup for hot butter or seasoning sauce.

Figure 1 Hot beverage cups (left) and Condiment cups (right) processed from thermoforming of PHA and PHB [5]

A process concern material reengineering approach known as *blown forming*, which material stock is loaded as liquid and then blown with pressurized air toward the sidewall of the mold. The result of this cast is the negative space that was the imprint from the inside. Conventional material such as LDPE or HDPE show smooth surface because of the higher blow up ratio, for which allow more complicated shape blown inside the mold. In Figure 2, the material processed with PHA and PHB through blown forming has resulted in a shape that has been an unconventional use of bio-based plastics with this manufacturing process. Since PHA and PHB properties allow constant melting strength, the additional process used of these materials have also yielded a steady heating and cooling temperature range prior and after the production process of the material. Comparing with conventional materials in the process of blown forming, PHA has tensile strength at 3.2 kpsi, while LDPE and HDPE may have ranged from 1.0-2.2 and 2.6-6.5 [6], respectively. Other categories such as modulus level, tear strength, and fragility percentage per volume, has also indicated the processes of PHA and PHB with fixed number unlike the rest of the conventional materials, which show minimum and maximum ranges of allowances. Nonetheless, the result from the forming of PHA and PHB falls between the ranges of minimum and maximum calculation of other materials, which demonstrate the acceptable range of PHA and PHB as a suitable material for manufacturing processes such as commercial plastics like PE.

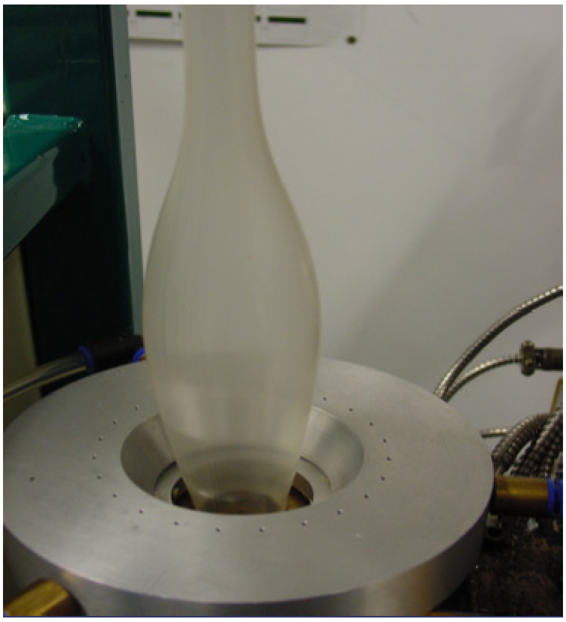

Figure 2 Design piece from “blown forming” of PHA and PHB bioplastics [5]

3. PLANTS EVOLUTION TO MANUFACTURING SOLUTIONS

As mentioned, cornstarch and sugarcane are two of the main renewable materials in forming PLA. This is evident in PHA and PHB production, where these two materials have been parts of the development to improve bio-based materials for the use in the design and engineering industry and to also raise awareness of environmental issue on excessive waste from consuming products made from non-biodegradable plastics. As alternative materials that defining solution to match the demand of current industrial trend of globalization, or sustainable design, solutions that reflect the understanding of natural as well as engineered properties of the materials have been established as a demand for current design practices. Therefore, in the sense of design concern on environmental issues through the use of bio-based materials, this design philosophy is an essential solution to the method of producing innovative design methodologies.

Interior design solutions of automotive industry evolution that modeled after the surrounding nature and use of organic materials are the focus of the evolutionary applications of the bio-based materials. Using the idea of carbon based element, example of bioplastic applications such as PLA, PHA, and PHB, which are engineered from corn and sugarcane are used to signify the design idea and possible directions of designing automotive component and accessories. Beginning with natural structure of corn to the development of bio-based materials to design ideas of using hemp in transportation design, the examples of small products are used as fundamental reasons for designing toward identity of bio-based products design methods.

According to several researches on corn or maize starch, these natural materials have unusual features, which are the nature of *transposons*, a gene exchange with capability of having survival characteristics when relocating with other genome where mutation is also favorable [6]. This exchange of gene is considered a powerful tool for tagging, identifying as well as isolating any of the corn’s gene when classification of the gene is the focus. Since this variation in the gene of such materials can easily be detected and classified, scientists and researchers value the identification aspect, a task that could be accomplished without complicated classification system. Designing with materials from natural resources detect this similar gap and attempts to create possible connection of design applications from natural and synthetic materials.

On a more direct application where a use of natural plant has been explored toward automotive design, the University of Guelph, Canada applied the use of hemp with the public bus seat. The project was intended to cut down on extra access materials as bus seats have short live on such strenuous public use and much of its disposable parts end up as waste in landfills. In Figure 3, this product demonstrates the unity of design strategy, which aimed to reproduce new waste products for the future transportation solutions. The project led by David Hume, who ventured on gathering resource made to extend a suitable life ratio per usage as well as collecting materials that have sustainable design possibilities. Within this work, hemp fiber was used with resin solution to create the form that is designed to initially meet the objective idea of a seat for mass production. This initiative approach generated the idea to further develop an environmentally friendly persona for Mass Transit System. In addition, any in-progress or established programs that implemented a global environmental concern have response with more addition of natural fibers as composite materials into products for vehicles. For example, the average European car contains 20 kilograms of bioproducts. Cornstarch slurries are used in the molding of rubber tires and sparkplugs, plant-based plastics are transformed into car mats and air bags, while jute, hemp and flax are mixed with polypropylene to build car interiors.

Figure 3 Part of hemp and glass reinforced plastic bonded with resin solutions for bus seat [7]

Other example that benefits the development of natural resource into useful material in lowering the waste has been a use of PLA, as an idea on producing mobile phone accessories to sustain a biodegradable quality. Although seemed as an ordinary design solution for phone casing, a functional case with alternative materials appeared to be a good design and engineering solution for the amount of excess trash gained from an un-used case. In Figure 4, the phone cases are produced by conventional injection molding, where small details can also be fulfilled with the quality of PLA properties that allow parts to be built through layering the materials with reinforcing *kenaf fibers* and shaping allowances that support the design demanded for detail features. Some companies even design cases with embedded dried flower seeds, which encouraged users to dispose the un-used case in the flower pot and with little care of watering, the seeds will then

Figure 4 Phone casing and the control of color consistency of the products [5]

grow into a flower or a plant. This technology reflects the care for the environment. At this point a design with the use of alternative bioplastics should be considered. As for the bio-based materials developed for use on day-to-day products, automotive industry have also begun to explore design aspirations that demonstrated cares for the natural resources and the future of the design with a bio-based methodology.

4. AUTOMOTIVE DESIGN FROM BIO-BASED PRODUCTS

Green or sustainable design philosophy have improved ranges of natural and bio-based plastics similar to the properties of PET or ABS. The idea of combining plastics and other natural or synthetic materials are not so new, such as the idea of engineering composite materials in the manufacturing of automobiles. For example commercial car such as BX Citron 1983, was built with composite materials of glass and polymer, a combination of polyamide and polyester. Additional design solution appeared on the formula-one circuit, a team like Ferrari, where body weight has been an issue until the use of carbon fiber, epoxy resin and NOMEX honeycomb were utilized to lower the mass volume weight and also lower the cost of part productions [8]. Since then the idea of combining materials has become part of the design philosophy. Nonetheless, those materials are not acceptable in the world of current automotive development and further research is required in order to design a new vehicle with green technology concept. In Figure 5, the work of Mercedes Benz and Daimler Chrysler car interior has demonstrated the use of natural fiber as an alternative material. The number of sole purposes, which gave the green light for the natural fibers exploration in automotive, were demands for Lightweight parts and good recycling possibilities. According to Johnson Controls, with natural fiber composites, car weight reduction up to 35 %, where this can be translated into lower fuel consumption and thus lower environmental impact. In addition, natural fiber based composites also offer good mechanical performance, good formability, high sound absorption and cost savings due to low material costs [9].

Figure 5 Interior components made of natural fiber composite for E Class car [9]

The exterior of the vehicle has also been a significant avenue for design to define the combination of material composite between natural fiber and bio-based plastics. Despite the limited application of natural fiber for exterior of a vehicle due to the low strength expectation and lack of heat resistant that concerns over natural fiber consistency, and fogging and odor emission and processing temperature limits of 200°C [10], automotive companies have addressed a design philosophies to explore the limitation and potential of bio-based materials for the vehicles [7]. Most recognized fiber used in the automotive industry are Flax, Hemp, Kenaf, Jute and Sisal. From the most common process, fibers are embedded in polypropylene or acrylic polymer matrices or combined with polyurethanes. Natural fiber reinforced polypropylene (NF/PP) composites can be delivered as needle punched sandwiches and further molded to a desired shape and thicknesses. This kind of lightweight and environmental friendly composites is very popular in the interior applications [9].

The ability of molding NF/PP is suitable for broader ranges of application, especially in the design of interior trims. Material engineer, Krauss-Maffei developed a long fiber injection molding process and adapted it in a way that fiber like hemp, flax or kenaf can be processed into polyurethane moldings. According to Krauss-Maffei, these natural fiber composites can offer weight savings of about 15% when compared to glass fiber reinforced plastic parts. Many car interior applications use compression molded polyurethane—natural fiber based materials from Bayer, which combines good performance and low energy consumption processing ability [11]. As the idea of developing and executing the design with bio-based plastics and natural fiber, leading companies have developed the idea of vehicle design to let consumer realize the significant changes in environmental issue. These are concerns for the fuel use, the purchasing selection of more environmentally friendly vehicle, and also to the after life of a vehicle. In Figure 6, Bayer has developed a new type of vehicle that mainly used bio-engineered plastics which are a strength of metal alloy. A concept car known as "eXasis" extended the production limitation of conventional metal on the exterior body and panels. The vehicle designed by Rinspeed, claims to cut emission or almost yield 0% CO_2 emission with 150 horse power and a top speed of 210 km/h.

Figure 6 "eXasis" concept car by *Rinspeed*, which employed Bayer polycarbonate plastics [12]

The eXasis exterior body, which uses proven Bayer Material Science polycarbonates for the transparent body has the similar finished property to that of PLA as combined with kenaf fiber. By revealing the once hidden mechanical components, the translucency helps provoke the idea of building a better relationship between human and a machine that foster the idea of care and better understanding of the intricate mechanism of the vehicles. The decision of translucency also confronts the consumer (driver) to directly engage in the actual functionality of the vehicle. This reaction helps reinforce the idea of concern and care for living surrounding and eventually the role that everyone should watch over one another as the guardian of the social impact on future environmental issues, such as the use of alternative materials to cut down the energy consumption or the decomposing of excess waste from products that have been produced and consumed.

5. CONCLUSIONS

Current vehicle design processes are organized toward the concept for sustainability. Yet concept cars are like a playing field without purposes, where engineers and designers are allowed to express their vision on the future of automotive innovation, they demonstrate lesser concern for the environment. Bioplastics are a good example in response to the global issue such as CO_2 emission and the afterlife of the products. The use of PLA may take part with combining the kenaf fiber to form a new kind of material, both for external and interior pieces. Figure7 shows the quality of translucent surface finished of a light cover using the combination of PLA and NF/PP for lights cover or interior trim. The use of PHA and PHB can benefit the automotive industry since its manufacturing process and physical property does not require new machine but can work with the already existing conventional system. At this point, designer, scientist, and engineer agree that engaging in exploration of alternative materials can save the cost of vehicle production by half. Certainly, the extensive researches on environmental safe manufacturing processes and life cycle of bio-based product have made the claim of car design methods into today society. The quality of future vehicles have now gone toward a new vehicle with more concern on the importance of environmental issues in the 21^{st} century.

Figure 7 Rear light, produce from polycarbonate

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