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Application of Biodegradable Polymer to Construction Materials

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Abstract*— The mechanical properties of biodegradable construction materials were investigated, and their possible methods of performance evaluation were introduced. Even though poly(butylenes adipate-co-terephthalate) (PBAT) has a higher elongation at break than most biodegradable polyesters, its extensive application is limited because of relatively slow biodegradation speed. To accelerate the biodegradation of PBAT, starch was melt-mixed with PBAT. According to previous studies, their biodegradation speed increased with addition of starch to polyesters but tensile strength of the blends significantly decreased. To overcome the drawback, organoclay was added to the blends in this study. Addition of 1wt% orgaoclay into the blends improved the tensile modulus and tensile strength. Nanocomposite materials made by mixing PBAT, starch and organoclay can be applied to vegetation mats which normally require keeping its function until seeds sprout and plants settle in soil, and their production process was introduced in this study. Additionally, the performance evaluation of possible biodegradable construction materials was summarized by systematical methods. The requirement conditions for vegetation mats was first arranged and then transferred into required performance. The test performance was classified based on the KS ISO standards from non-biodegradable plastic test methods. Finally, the environmental performance was proposed by evaluating the life cycle assessment of biodegradable construction materials from the production of raw materials to the decomposition of vegetation mats.

***Index Terms*—Life cycle assessment, Organoclay, Poly (butylene adipate-co-terephthalate, Starch, Vegetation mat.**

I. INTRODUCTION

Many policies and plans have been globally proposed to reduce carbon emissions. Korea is ranked 9th among OECD countries for emitting greenhouse gases. Therefore, Korea has to reduce greenhouse gas. It has to drastically increase demand on developing carbon-reduced construction materials and carbon virtuous cycle products by making low carbon green growth a national agenda to reduce greenhouse gas [1]. It also needs to support the development of various eco-friendly materials. Now, the reduction policies of non-degradable products that are now widely popular are being planned as well as policies to promote the development and use of various biomass products [2]. As there has been heightened social recognition about environment problems, R&D on biodegradable plastics and the diversification of products have been in progress and the paradigm on eco-packaging is now changing. In particular, biodegradable plastics are expected to become rapidly industrialized as their range is expanding to biodegradable plastics and biomass plastics that can overcome the limits in industrialization, including the degradation of existing biodegradable plastics, price competitiveness, and reuse. Within 2 ~ 3 years if possible, products that are expected to be commercialized including the following: food containers made of bio-plastics, low carbon tools and materials, materials for agriculture and horticulture, and industrial products [3]. In the future, the white bio industry including biodegradable and biomass plastics will be regarded as a promising industry in respect of its potential in markets and growth. Though the level of domestic technology is not behind that of foreign countries owing to the activation of polymer fabrication and the development of eco-friendly construction materials by continuous green growth policies of the government, the dependence on technology originating from overseas is relatively high. Now, it needs to create various markets by making use of the excellent domestic production and fabrication technology while reducing the difference between foreign and domestic technology. In particular, the Ministry of Land, Infrastructure and Transport is analyzing the carbon emissions in all stages of civil and construction facilities as well as studies and policies on the minimization of carbon emissions during their whole life. In 2010, the land and ocean R&D development policies, low carbon construction materials through time-controlled biodegradation was selected as unique technology in the construction fields among future key technologies [4]. In respect of the life cycle, development of technology that limits the generation of construction waste and reuses them is well consistent with green growth plans for construction technology. Many concerns with the biological fields as important future projects in the USA and Europe require ongoing research into alternative petroleum resources that will become exhausted in the future. In this study, the feasibility of biodegradable polymers as a construction material was evaluated through experiments on their mechanical properties. In addition, methods for the performance evaluation of vegetation mats that are feasible for biodegradable construction materials were made, and a methodology for their environment friendliness was also built through all the processes from manufacturing through degradation.

II. MECHANICAL PROPERTIES OF BIODEGRADABLE POLYMER

One of the commercialized biodegradable polyesters is poly (butylene adipate-co-terephthalate) (PBAT) which is

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aliphatic-aromatic co polyester. PBAT is prepared by polycondensation reaction of 1,4-butanediol with both adipic and terephthalic acids. Even though PBAT has a higher elongation at break than most biodegradable polyesters, its extensive application is limited because of relatively slow biodegradation speed. Mixing PBAT with starch can increase a biodegradation speed. Starch is readily available, inexpensive and has a very fast biodegradability [5]-[7]. Also, starch is obtained from renewable sources. According to previous studies, their biodegradation speed increased with addition of starch to polyesters but tensile strength of the blends significantly decreased [8]-[10]. This is due to the poor interfacial adhesion between the hydrophilic starch and the hydrophobic PBAT. In recent years, polymer/organophilic layered silicate (organoclay) nanocomposites have attracted considerable attention from both an academic and application point of view due to their improvement in material properties. Owing to the nanometer thickness and extremely high aspect ratio of silicate layers, the nanocomposites exhibit improvements in their mechanical, thermal and barrier properties [11]-[13]. The main focus of this study is to increase tensile strength and tensile modulus of PBAT/starch with addition of organoclay. PBAT was melt-mixed with starch and oganoclay in a kneader, and then the mixtures were compression-molded. The effects of organoclay content on the tensile modulus and tensile strength of PBAT/starch composites were examined in detail.

III. MANUFACTURING METHODS OF PBAT/STARCH/ORGANOCLAY NANOCOMPOSITES

The PBAT used in this study was purchased from S-EnPol Co. Oxidized corn starch purchased from Samyang Genex Corp was also used. According to the provider, the oxidized starch was produced by reaction of starch with hypochlorite, resulting in partial conversion of hydroxyl groups of starch to carboxyl groups. Organ clays were purchased from Southern Clay Products (U.S.A) under the trade name of Cloisite 20A and Cloisite 30B. Organic modifier of Cloisite 20A and 30B is dimethyl, dehydrogenated tallow, quaternary ammonium and methyl tallow bis-2-hydroxyethyl quaternary ammonium, respectively. The characteristics of materials used in this study are shown in Table 1. PBAT, starch and organoclay were dried in the oven for 24 hours at 50°C before their nanocomposites were manufactured. PBAT and starch were melt-mixed with or without organoclay in a bench kneader (Irie Shokai Ltd., Japan) at 20 rpm for 10 min. Mixing temperature was 130°C. Mixing ratio of PBAT/starch was fixed at 80/20 wt%. Two levels of organoclay content in the PBAT/starch/orgnaoclay nanocomposites were selected: 1 and 3 wt%, based on the total weight of PBAT and starch. The obtained nanocomposites were compression molded at 130 °C for 5 min for the testing samples.

Table 1 Important Characteristic of the Materials

Materials	Supplier	Characteristics
PBAT	S-EnPol Co., Korea	Melt flow index (2.16kg, 190°C): 2.0-4.0 g/10min_ Tg: -30 ~ -25°C Tm: 127 ~ 132°C Density: 1.12 g/ml
Corn starch	Samyang Genex Corp., Korea	Viscosity: 8-12 cps Specific gravity: 0.53
Cloisite 20A	Southern Clay Products, U.S.A	Modifier concentration: 95mequiv/100g
Cloisite 30B		Modifier concentration: 95mequiv/100g

IV. EXPERIMENTAL RESULTS

A Universal Testing Machine (Model 4466, Instron Co., and USA) was used to obtain the tensile properties of the nanocomposites at room temperature. The crosshead speed was 500 mm/min. All measurements were performed for five replicates of specimens (thickness: 2 mm) and averaged to get the final result. Fig. 1 and 2 show the tensile modulus and tensile strength of PBAT/starch/organoclay nanocomposites as a function of organoclay content, respectively. With increasing organoclay content, the tensile modulus of the nanocomposites increases.

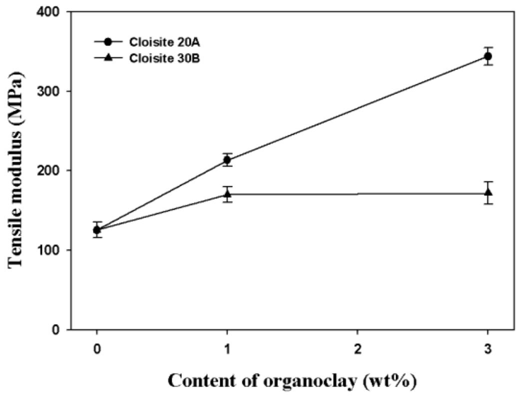

Fig. 1 Tensile modulus of PBAT/starch/organoclay nanocomposites as a function of organoclay content

The tensile modulus of PBAT/starch/Cloisite 20 A nanocomposites is higher than that of PBAT/starch/Cloisite 30B nanocomposites. Over the tensile modulus of PBAT/starch (80/20), 170 and 270 % improvements are observed with addition of 1 wt% and 3 wt% Cloisite 20A, respectively. Generally in composites, their modulus is related to the dispersion of fillers and interaction between fillers and matrix. Well-dispersed fillers and high interaction between fillers and matrix give higher enhancement of modulus to the composites.

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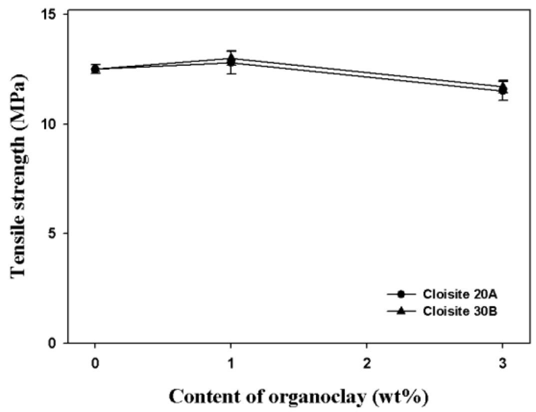

Fig. 2 Tensile strength of PBAT/starch/organoclay Nan composites as a function of organoclay content

Also, high aspect ratio of organ clays contributes to the significant improvement of modulus for the nanocomposites. The tensile strength of PBAT/starch (80/20) slightly increases with addition of 1 wt% organoclay. However, the tensile strength of PBAT/starch (80/20) decreases with addition of 3 wt% organoclay. Fig. 3 shows the elongation at break of PBAT/starch/organoclay nanocomposites as a function of organoclay content. With increasing organoclay content, elongation at break decreases. The decrease of elongation at break is generally observed for the polymer/organoclay nanocomposites. This is due to decrease in ductility with increased stiffness.

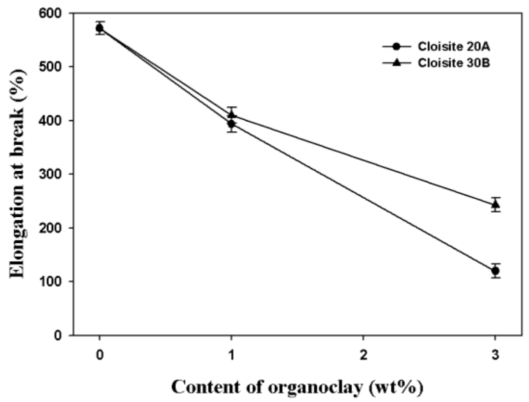

Fig. 3 Elongation at break of PBAT/starch/organoclay nanocomposites as a function of organoclay content

V. APPLICATION OF CONSTRUCTION MATERIALS

A. Possible Application of Biodegrdable Polymers

Recently, the direction of domestic river improvement projects were set up to restore natural rivers after the importance of the river environment had been recognized. Avoiding artificial materials for revetments of rivers, natural materials and vegetation were introduced to improve the landscape of rivers and to restore the nature. A typical revetment construction method used in construction works was vegetation mat revetments. Applying slope revegetation technology with good soil productivity, moisturizing capacity, and permeability to devastated zones where once impossible for plants to grow, such as hard rocks, soft rocks, and weathered rocks generated from road construction and land development, and other cut slopes, vegetation bases for preventing slope loss and falling stones can be made [14-15].

Composite materials made by mixing PBAT and starch can be applied to construction sites. Among them, a realistic possibility for biodegradable polymers will be a type of vegetation mat which normally requires keeping its function until seeds sprout and plants settle in soil. The vegetation mats have two features through afforestation on slopes including rivers, banks, small rivers with fast flow, the edges of lakes, reservoirs and roads. The primary feature is the prevention of erosion and soil loss, a protection of bank slopes against flooding. The secondary features include fast environment restoration by eco-friendly afforestation.

B. Vegetation Mats

Table 2 shows the production processes of vegetation mats made of PBAT and starch. First step was input of raw materials to mixing container and then started to mix until all raw materials were uniformly mixed about 5 to 10 minutes. The mixed materials were moved to an extruder, which melted and agitated it with a heater and then weaved threads to various types of forms. The mats were cooled and rolled. It combined nonwovens or pulps on the bottom and input seeds with eco-friendly organic fertilizers. Then, jute nets were finally fixed on the top to make a stable structure for sprouting seeds. The products were completed in a cylindrical form by bonding by sewing with the size of 63 m × 2 m.

C. Performance Evaluation for Vegetation Mat

To consider the present trend that new materials, new products, and the new technology of various biodegradable plastics can be developed as well as to promote the development of economic and efficient products, it is necessary to introduce a performance criteria by proposing functional requirements and performance requirements and by defining a verification method. In this section, we proposed a process in which the required items by stage are derived to determine the performance evaluation methods of composite vegetation mats to be developed before their applications. Based on conditions given in the process of selecting biodegradable construction materials, Fig. 4 shows a flow chart to apply the performance criteria of construction materials through quantification processes of requirements.

Processes to select the evaluation items of biodegradable vegetation mats were divided into three steps. The first step is the clarification of required performance of materials. Materials compose of final products. After the performance required at application sites was clarified, the required performance of the material is obtained by transforming the performance. In this case, it needs to clearly arrange material to select or conditions of applied products.

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Table 1 Production Process of Vegetation Mats

Production Processes	Picture	
Preparation of raw materials & mixing		
Materials extrusion & heating		
Weaving thread		
Cooling & rolling		
Sewing & final rolling		

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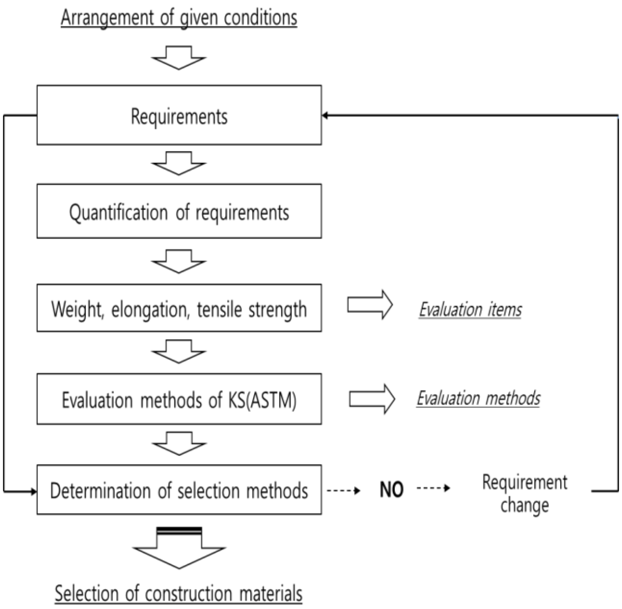

Fig. 4 Process to derive performance criterion of vegetation mats

The second step is to clarify performance of materials. Selecting material suitable for required performance obtained in the first step, it needs to clarify performance of the material and to select or define test methods fit to required performance. The third step is to compare required and owned performance. Comparing required performance to the material obtained in the first step with owned performance in the second step with respect to consistent criteria, optimal material is selected. Because it is impossible to obtain material that satisfy all required performance, it is possible to select material after changing the level of requirements and it also needs to use optimization theories and methods. Based on required performance items classified through a process in which the requirements of biodegradable composite vegetation mats are transformed to the required performance, Table 3 shows the setting in biodegradability measurement methods and test methods in the existing non-degradable plastics in compliance with the KS ISO standard test specifications. In the test methods of the vegetation mats, it requires these items for their setting: biodegradability, density, porosity, elongation, weight, thickness, tensile strength (length/width), the bearing capacity of the soil, absorption rate.

A. Evaluation Methods of Eco-Friendliness

Life Cycle Assessment (LCA) is an objective method of evaluating environmental effects to search for measures on environmental improvement, quantifying amounts of energy and material that are consumed and emitted in all stages of a product, a process, and an activity [16]-[17]. Fig. 5 shows the evaluation procedures of environmental impact for vegetation mats in the LCA. By dividing the life cycles of biodegradable construction materials into four stages (material production, construction, use and maintenance, and biodegradation stages), the analysis objects were limited by the stage and evaluation methods of environmental impact as well as data collection methods determined. The "Cradle to Gate" systems in the LCA of vegetation mats were set from the production stage of input materials to the biodegradable construction materials until the degradation stage in which construction materials are completely degraded (Fig. 6).

Table 2 Determination of Methods to Evaluate the Performance of construction Materials

Required performance items	Test methods
Biodegradability	• KS M 3100-1, KS M ISO 14855-1
Porosity	• Measurement of internal voids in the whole volume
Density	• KS M ISO 1183-3
Elongation	• KS K 0743, KS K 0520, KS K ISO 10319
Weight	• KS K ISO 9864, KS K 0514
Thickness	• KS K ISO 9863
Tensile strength	• KS K ISO 527-1 or 2, KS K ISO 10319
Bearing capacity of soil	• Pullout tests
Absorption rate	• KS M ISO 2896

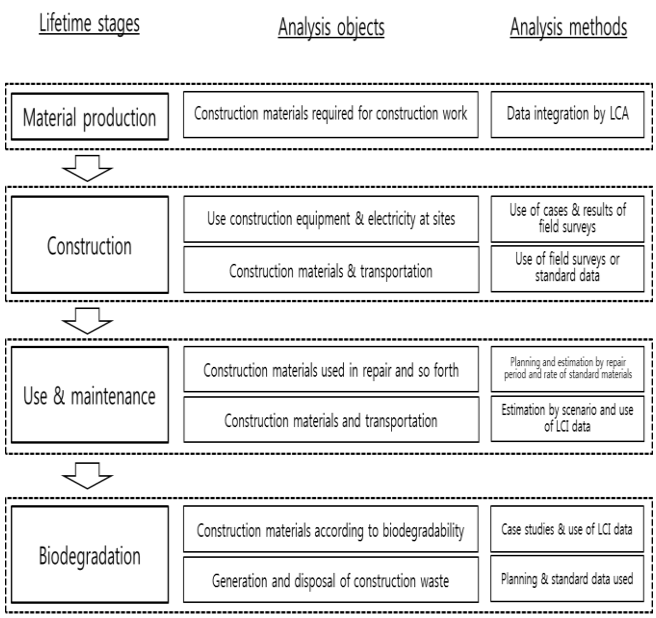

Fig. 5 LCA evaluation process of biodegradable materials

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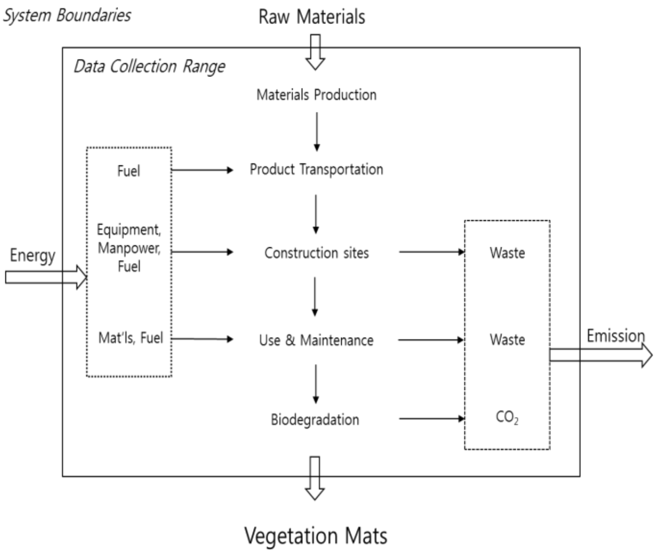

Fig. 6 Boundary of estimation system for lifetime

The material production systems include all processes of producing finished or half-finished products for construction materials to be used to make vegetation mats, by consuming resources and the energy necessary for production, including the collection and fabrication of raw materials, and the production of products to produce construction materials. The construction systems include: from the transportation process of materials from factories to construction sites until the completion of vegetation mats using construction materials, energy, and equipment in all construction processes. The use and maintenance systems include processes in which vegetation mats are preserved by additional repairs before they are completely degraded. The biodegradation systems include processes in which the lifetime of vegetation mats ends and the mats are biologically degraded.

VI. CONCLUSION

In this study, the feasibility of biodegradable polymers as construction materials (vegetation mats) was evaluated based on results of experiments on basic mechanical properties of the polymers. For vegetation mats that are probable to be used as biodegradable construction materials, methods for determining performance items and evaluating performance were proposed together with methods for evaluating eco-friendliness through all processes from production until degradation.

1 . The mechanical properties of PBAT/starch/organoclay nanocomposites such as tensile modulus, tensile strength, and elongation at break were obtained in experiments.

2 . Over the tensile modulus of PBAT/starch (80/20), 170 and 270 % improvements are observed with addition of 1 wt% and 3 wt% Cloisite 20A, respectively.

3 . The tensile strength of PBAT/starch (80/20) slightly increases with addition of 1 wt% organoclay. However, the tensile strength of PBAT/starch (80/20) decreases with addition of 3 wt% organoclay. With increasing organoclay content, elongation at break decreases.

4 . PBAT/starch/organoclay nanocomposites can be applied to vegetation mats which normally require keeping its function until seeds sprout and plants settle in soil, and their production process was introduced in this study.

5 . Through the classification of typical construction methods for slope stabilization, a evaluation method was determined through the transformation of required performance in the processes to derive performance evaluation of eco-friendly vegetation mats.

6 . Typical required performances were classified into tensile strength, elongation, porosity, biodegradability, density, thickness, weight, absorption rate, bearing capacity of soil. Test methods suitable for each performance were arranged according to KS ISO.

7 . Classifying the LCA for biodegradable construction materials into four stages, including material production, construction, use and maintenance, and biodegradation stages, eco-friendly evaluation procedures for analysis objects and methods were built for each stage by determining system boundaries.

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