

AC 2008-18: A LABORATORY SESSION DEVELOPMENT: STUDY OF MECHANICAL PROPERTIES OF PETROLEUM-BASED PLASTIC COMPOST BAG AND BIODEGRADABLE PLASTIC COMPOST BAG

Seung Kim, Rochester Institute of Technology

Dr. Spencer Seung Kim is Associate Professor in Manufacturing and Mechanical Engineering Technology/Packaging Science Department and works as Associate Director in American Packaging Corp. Center for Packaging Innovation at RIT. His research areas are in composite materials synthesis and characterization. Dr. S. Kim graduated with M.S. (1989) and Ph.D. (1993) from University of Illinois at Chicago.

Bok Kim, Div. of Advanced Materials Engineering, Chonbuk National University

Dr. Bok H. Kim is Professor, Director of Hydrogen Fuel Cell Research Center in Div. of Advanced Materials Engineering at Chonbuk National University, S. Korea. Dr. B. Kim has worked in the areas of synthesis of SOFC materials(anode, cathode and electrolyte materials) and R&D of Micro-SOFC for prototype cathode materials for lithium secondary battery(LiNiO₂ system, LiMnO₂ system), and MLCC for capacitor and temperature compensating capacitor for many years.

A Laboratory Session Development: Study of Mechanical Properties of Petroleum-Based Plastic Compost Bag and Biodegradable Plastic Compost Bag

Abstract

There is a global interest in replacing oil-based synthetic plastics with biodegradable materials in order to enhance the biodegradability of the plastic materials and to reduce the amount of persistent plastic waste. To develop an undergraduate laboratory session in a materials laboratory course, this paper deals with investigating the mechanical properties of two types of the plastic films under controlled testing conditions: the tensile properties of petroleum-based compost plastic bag and biodegradable plastic compost bag. The effects of different strain rates (e.g. speed of testing) on the tensile properties of petroleum plastic films and biodegradable plastic films are also investigated for comparison.

Introduction

Many of today's products are manufactured from petrochemicals and are not biodegradable. As these products are based on petroleum-based synthetic materials, they are a significant source of the environmental pollution and waste in nature.

Biodegradable polymers, which are mostly derived from renewable resources, become attractive to address the sustainability of materials in commercial applications, since they enter the normal geo-chemical cycle over intended life time.^{1,2} In addition, the biodegradable polymers can perform the intended functions as designed and can be manufactured by most conventional plastics processing technology.³

The demand for biodegradable materials in various product applications, such as, food packaging, personal care products, marine applications, automobile parts, and bio-medical products, has rapidly increased due to a combination of high crude oil price, government policy, environmental concern, solid waste disposal cost, and public interest. Recently, the government, private sectors, and universities are exploring many programs in research and development of biodegradable materials technology to reduce the dependency of foreign petroleum resources. The issues of depolymerization scheme, economics, and waste management of the biodegradable materials are addressed from scientific and consumer standpoints in order to gain acceptance as well. For example, San Francisco recently banned conventional plastics bags in grocery stores within the city limit.⁴ Other cities and states are now considering similar legislation. As a result, a lot of interest is focused in the use of biodegradable polymers in these bags.

There is an opportunity not only to utilize the sustainable resources in the production and application of biodegradable materials, but also to understand the full range of concerns in a new field in biodegradable materials technology. The aim of this paper is to develop

an undergraduate laboratory session for a materials laboratory course in a mechanical engineering technology program. The laboratory session concentrate on the study of mechanical properties in two types of the plastic films under controlled tensile testing conditions: petroleum-based compost plastic bag and biodegradable plastic compost bag.

Concepts in Biodegradability, Compostability, Renewability and Sustainability

L. Averorus reviewed multiphase biodegradable systems in which the term “biodegradable” means capable of undergoing decomposition into carbon dioxide, methane, water, inorganic compounds, or biomass in which the predominant mechanism is the enzymatic action of micro-organisms that can be measured by standard tests over a specific time period, reflecting available disposal conditions (ASTM standard D-5488).¹

The term “compostability” is the biodegradability of material using compost medium. Biodegradation is the degradation of an organic material caused by biological activity, mainly micro-organisms’ enzymatic action. This leads to a significant change in the biomaterial chemical structure. Depending on the standard testing method, the composting conditions (such as humidity, temperature, and cycle) must be understood to determine the level of compostability.⁵

Renewability is linked to the concept of sustainable development. The UN world Commission on “Environment and Development in our Future” defines sustainability as the development which meets the needs of the present time without compromising the ability of future generation to meet their own needs. Narayan reported that the manufactured products (e.g., packaging) must be designed and engineered from “conception to reincarnation,” the so called “cradle to grave” approach.^{4, 5}

Experimental Details

Materials

Two types of the compost plastic bag were investigated for the study: one type was a petroleum synthetic polymer film (commercial grade of high density polyethylene) of 0.001 in. (0.25 μm) thickness and the other was a biodegradable polymer film (commercial grade of poly (lactic acid)) of 0.001 in. thickness. These compost bags were purchased from the commercial market.

Testing Methods

Since tensile properties may vary with sample conditioning method, sample thickness, type of grip used, speed of tensile testing, and manner of measuring extension, the testing condition and sample preparation for the study were precisely controlled by the ASTM testing methods. The following ASTM standards were used for the sample preparation and tensile testing of the plastic films: ASTM Standard D618 and ASTM Standard D882.^{6, 7}

Sample Preparation and Tensile Testing

Since the materials of the compost bags were biaxially oriented to improve the tensile properties in the machine (MD) and transverse (TD) directions in blown film processing. The rectangular shape of sample film strip was cut by 6 in. long X 1 in. width X 0.001 in. thickness. The ten sample film strips were prepared and conditioned from each type of the plastic compost bags: five samples of the machine direction (MD) and five samples of the transverse direction (TD).

In general, the properties of plastics are influenced by testing environment (e.g. temperature and humidity), so film strip samples were conditioned at 23 ± 2 °C for 40 hours in controlled laboratory environment, prior to the testing.

The speed of testing can be determined from the experimental initial strain rate as specified ASTM standard D882. The rate of grip separation was determined for the purpose of the experiment from the initial strain rate as follows:

$$A = BC$$

Where:

A = rate of grip separation, mm (or in.)/min,

B = initial distance between grips, mm (or in.), and

C = initial strain rate, mm/mm·min (or in. /in·min).

The initial strain rates of the experiment were chosen at 2 in/in·min and 10 in/in·min in tensile testing. Thus, the calculated grip speeds at the initial strain rate of 2 in/in·min and 10 in/in·min were 8 in/min and 40 in/min, respectively (Table 1). The grip speed, initial grip separation, and initial strain rate for this study are summarized in Table 1.

Table 1: Grip speed, initial grip separation, and initial strain rate

Initial strain rate (in./in·min)	Initial grip separation (in.)	Grip speed(in./min)
2	4	8
10	4	40

In order to eliminate the slippage of the film sample, both ends of the rectangular strip (6 in. long X 1 in. width X 0.001 in. thickness) were wrapped with papers of 2 in. long X 1 in. width such that, they could be tightly positioned in the two testing grips of the tensile testing machine without slippage. Otherwise the ends of the plastic sample film would slip away from the testing grips during the testing.

After tensile testing, the tensile strength values of each sample film strip were measured for analysis.

Results and Discussion

Figures 1 and Figure 2 show the engineering stress-strain behaviors of two types of the polymer compost bags, polyethylene (PE) bag and biodegradable compost bag, at a testing speed (e.g. grip speed) of 40 in/min. These stress-strain curves of the two types of compost bags exhibit typical ductile behaviors under tensile loading.

Figure 1 illustrates that the PE compost bag has a high plastic deformation characteristic (that is, a high elongation) with a high tensile strength as it fractures almost at the peak loading. Figure 2 shows the plastic deformation of biodegradable compost bag. This large plastic characteristic (e.g. strain) under tensile loading is similar to that of the PE bag: that is, the biodegradable bag has a high elongation in tension. However, the tensile strength of the biodegradable bag at 40 in/min is substantially lower than that of the PE bag. These results demonstrate that the PE bag would be tougher than the biodegradable bag in mechanical loading.

Figure 1: Typical engineering stress-curve of polyethylene (PE) compost bag at 40 in/min

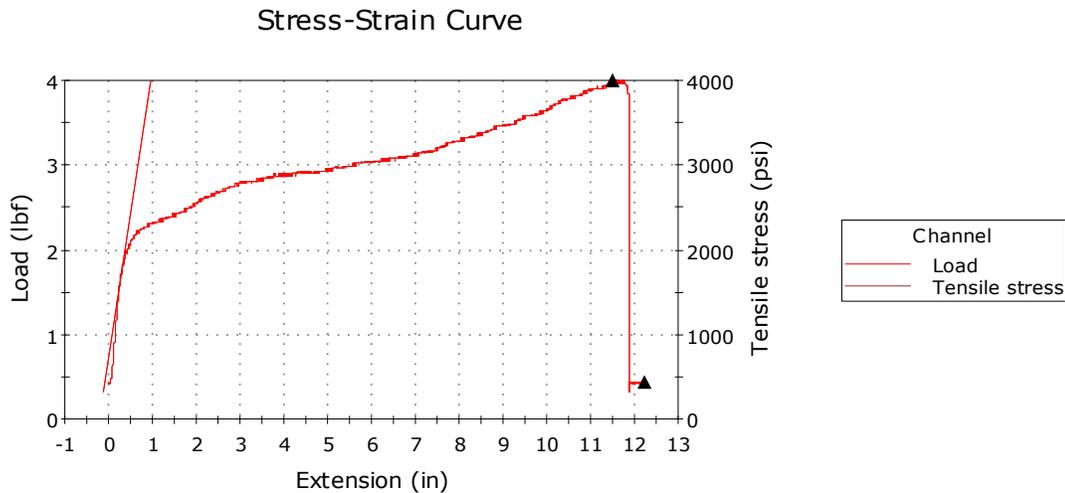


Figure 2: Typical engineering stress-curve of biodegradable polymer compost bag at 40

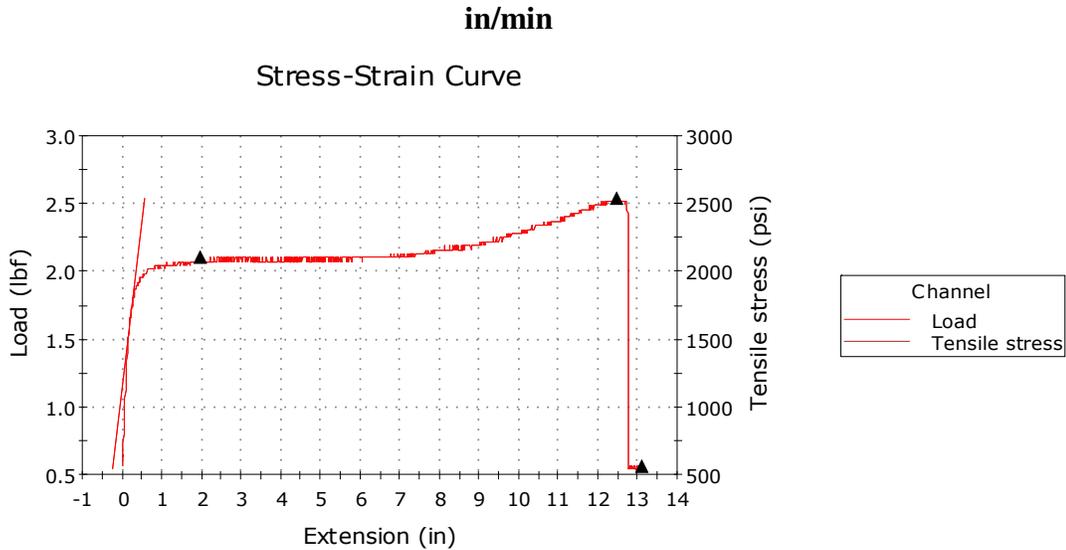


Table 2 and Table 3 summarize the tensile strength values of the polyethylene (PE) compost bags and the biodegradable polymer bags in various testing conditions. Figures 3, 4, and 5 are the graphical presentations of the experimental data (e.g. the mean values of tensile strength) obtained by statistical analysis for comparison.

Table 2 shows the values of the tensile strength of the PE compost bag and biodegradable polymer bag at 8 in/min of the speed of testing (e.g. grip speed). The table summary includes the mean, maximum, minimum, and standard deviation. The mean values of the tensile strength of PE compost bags in machine direction (MD) and transverse direction (TD) at 8 in/min are 25.95 MPa and 17.42 MPa, respectively (Figure 3). The mean values of the tensile strength of biodegradable compost bags in MD and TD at 8 in/min are 15.87 MPa and 10.24 MPa, respectively (Figure 3).

The tensile strength values of the PE bags are greater than those of the biodegradable bags in MD and TD at 8 in/min. For example, the mean value of the tensile strength of the PE bag in MD is 39% higher than that of the bio-bag (Figure 3). Figure 3 shows that the tensile strength values of both two different types of the compost bags in MD are greater than those of the bags in TD. This indicates that the tensile strength of the polymer compost bags is directly affected by the direction of the biaxially-oriented polymer film.⁹

Table 2: Tensile Strength (MPa) of Compost Bags at 8 in/min

Material	Mean	Max	Min	Standard Deviation
PE Bag (MD)	25.95	28.36	22.44	2.28
PE Bag (TD)	17.42	18.16	17.14	0.42
Bio. Bag (MD)	15.87	18.77	11.83	3.69
Bio. Bag (TD)	10.24	10.41	10.00	0.17

The similar results, as described in Table 2, were observed in the tensile strength of the PE and biodegradable compost bags at 40 in/min of the grip speed (Table 3). Figure 4 shows that the PE bags are stronger than the biodegradable bags in MD and TD at the grip speed of 40 in/min. For example, the tensile strength of the PE bag in MD is 31% higher than that of the bio-bag at 40 in/min. As shown in Figure 4, for both PE and biodegradable compost bags, the tensile strength in MD is greater than in TD.

Figure 3 and Figure 4 show that the tensile strength of the two different types of the polymer bags is related to the direction of the biaxially-oriented polymer films regardless of the grip speed in tensile testing. These results indicate that there is a relationship of structure-process-property in the biaxially oriented compost bags. For example, biaxially oriented polyethylene polymer films had better mechanical properties in both directions (i.e., MD and TD) of the film as compared to unoriented and uniaxial oriented films.^{8,9} The advantage of biaxially oriented polymer films resulted in the balance of properties by simultaneous stretching during blown film process.⁹

Table 3: Tensile Strength (MPa) of Compost Bags at 40 in./min

Material	Mean	Max	Min	Standard Deviation
PE Bag (MD)	28.32	31.22	26.32	1.86
PE Bag (TD)	17.67	18.16	16.12	0.88
Bio. Bag (MD)	19.59	22.24	16.53	2.49
Bio. Bag (TD)	13.59	14.49	12.85	0.74

Figure 5 presents the effects of the grip speed (e.g. strain rate) on the tensile properties of the polymer bags. In the tensile behavior of PE and bio compost bags, the higher strain rate corresponds to the higher tensile strength. The results also show that the strain rate in tensile testing affects the strength of the PE and the biodegradable bags in both MD and TD of the biaxially-oriented polymer films. Many studies reported that the strain rate affected the mechanical properties of polymeric materials.^{10,11}

Figure 3: Comparison of mean values of tensile strength (MPa) of compost bags in testing speed of 8 in/min

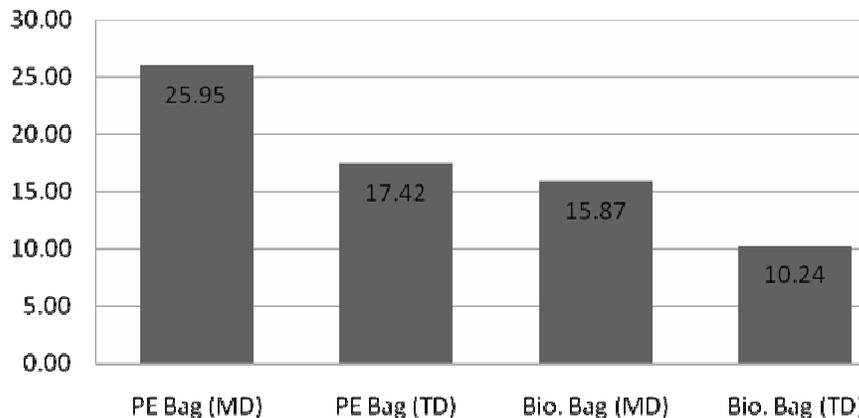


Figure 4: Comparison of mean values (MPa) of tensile strength of compost bags in testing speed of 40 in/min

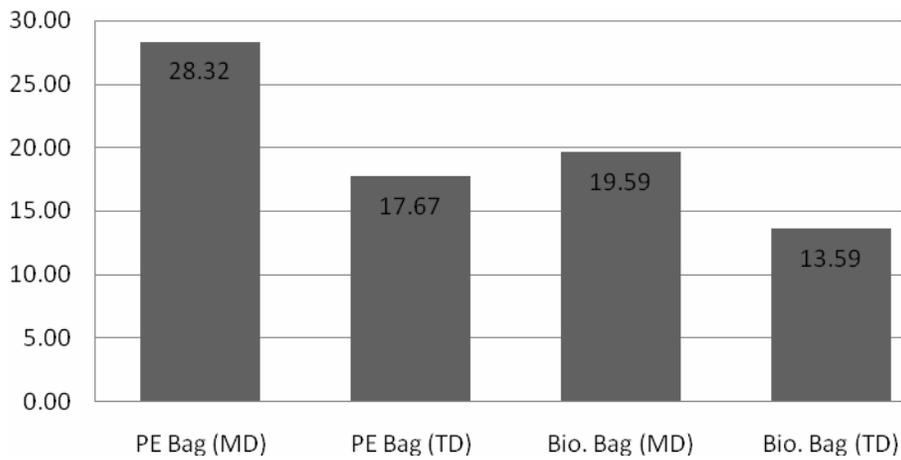
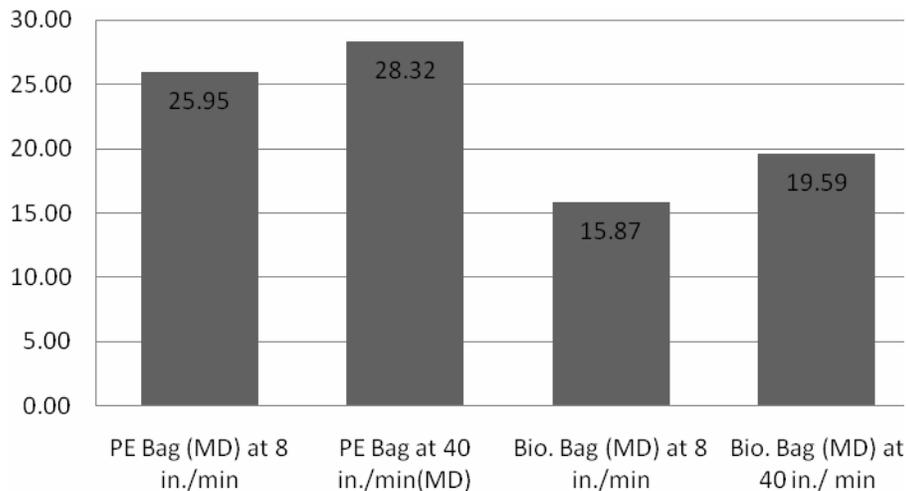


Figure 5: Comparison of mean values of tensile strength (MPa) of compost bags in the effect of grip speed (i.e., strain rate)



Approach in Laboratory Session Development

The laboratory course in materials and processes needs to focus on the problem solving approach interfaced with laboratory experiences. The course titled “Mechanical Engineering Technology Laboratory II” is a materials laboratory course to provide basic principles in plastics testing for the 3rd or 4th year students in the Manufacturing and Mechanical Engineering Technology programs at Rochester Institute of Technology (R.I.T.). The primary goal of the lab course is to introduce not only theories in plastic materials, but also to provide hands-on-experience in the ASTM (the American Society for Testing and Materials) standards in plastics testing. The development of lab contents

should cover the needs to give proper preparation so that students can deal with inevitable changes in materials science and engineering.

Some concerns reflected on the development of laboratory session are to enhance knowledge in materials, to develop laboratory skills, and to synthesize the course subjects. The experiment in “Study of Mechanical Properties of Petroleum-Based Plastic Compost Bag and Biodegradable Plastic Compost Bag” is that students understand how to utilize the instrument and measurement techniques by obtaining and analyzing the data in the comparison of polymers: petroleum based compost bag and biodegradable compost bag. In the experiment students learn how to draw conclusions from the results and develop skills to understand some fundamentals in the structure-property-process relationship of materials.

Conclusions

In the study, the relationships between the tensile strength, the orientation of the polymer film, and the grip speed (e.g. strain rate) were investigated in two different types of the compost bags: polyethylene compost bag and PLC biodegradable compost bag.

- The PE compost bag has a high plastic deformation characteristic (that is, a high elongation) with a high tensile strength.
- The PLC bio-bag has a high elongation in tension. However, the tensile strength of the bio-bag is substantially lower than that of the PE bag
- The values of the tensile strength of the PE bags are greater than those of the biodegradable bags in MD and TD.
- The tensile strength of the two types of the polymer bags is related to the direction of the biaxially-oriented polymer films regardless of the grip speed in tensile testing.
- The strain rate in tensile testing affects the strength of the PE and the PLC biodegradable bags in MD and TD of the biaxially-oriented films

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