Biobased Biodegradable and Degradable Plastics Effects on Recycled Plastics

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Introduction

We are living in the plastics age where plastics are replacing metal, wood, paper, and ceramic products in most industries today, including transportation, medical, retail, and electronic. The key feature of thermoplastics is the fact that the material can be heated and formed multiple times. Thermoplastics can be recycled if they are collected and then sorted by their recycling number, e.g., PET or PETE (Type1), HDPE (Type 2), PVC (Type 3), LDPE (Type 4), PP (Type 5), PS (Type 6), and Other Plastics (Type 7). In 2003, the total annual postconsumer plastic bottles that was collected in the United States increased to an all-time high of 1,667 million pounds.[1] The majority of recycled plastic is polyethylene terephthalate (PET or PETE) and high-density polyethylene (HDPE) for rigid containers. PET is used for bottles of soda pop and other drinking fluids. HDPE is used for plastic milk jugs. The PET and HDPE are easily separated during recycling reprocessing due to their density differences.

Biobased Plastics Overview

Biobased plastic products can replace traditional plastic products in many applications. Biodegradable plastic products can reduce the plastic waste in landfills if the plastic products are disposed of at appropriate composting operations rather than landfill. Biodegradable plastics, though, are not designed to disappear in landfills and should not be considered a solution to reducing waste in landfills.[2] According to the 2003 CA Waste Characterization Study, plastics contributed to 12% by weight of the waste stream for the commercial waste, 9.5% of the waste from residential waste, and 3.9% of the waste stream in self-hauled waste.[3]

Biodegradable polymers are those that are capable of undergoing decomposition into carbon dioxide, methane, water, inorganic compounds or biomass by the actions of micro-organisms. "Compostable" is a better term for truly biodegradable plastics. It is very important to understand that to be biodegradable should also mean that it occurs in a reasonable time frame. Unfortunately, many plastics claim to be biodegradable if a portion of it breaks down into small pieces or the organic portion of the plastic disappears in the soil. The fragmented plastic leaves small pieces in the soil and may take many decades to fully disappear. The key to understanding true biodegradability is to ensure that the plastic will behave like other organic materials in the soil, like leaves and sticks. Two independent organizations, the US Composting Council (USCC) and The Biodegradable Products Institute (BPI), jointly established procedures to verify the compostability claims of biodegradable products and created a "Compostability Logo" to verify the compliance with ASTM D6400 compostability standards.[4] Compostable biobased polymers are produced from natural materials, e.g., starch from corn, potato, tapioca, rice, wheat, etc., oils from palm seed, linseed, soy bean, etc., or fermentation products, like polylactic acid (PLA). The most common compostable biobased plastics are starch-based plastic bags and PLA rigid containers for cups, bottles, and clamshell containers. Biobag starch-based plastic bag is a wholly compostable polymer based on a blend of at least 50% starch with the remaining synthetic hydrophilic degradable polyester.[5] Polylactic acid (PLA) can be produced from corn starch through a fermentation process.[6] Other compostable plastic products for rigid products are made from PHA,[7] bagasse,[8] and cellulosic materials. A list of plastic resins and plastic products that are truly biodegradable are available at the BPI website.[9] Oxodegradable plastic bags are also available today to replace traditional LDPE plastic bags. The oxodegradable plastic bags are not biodegradable but are designed to break down into small pieces after exposure to oxygen. The smaller pieces may lead to environmental problems if they are consumed by animals or if the small pieces are scattered over the ground.

Trash bag and clear bottle recycling can be compromised if the compostable biobased plastics or the oxodegradable plastics are added to the recycling stream. Recently, NatureWorks published materials that claim that their PLA material can be recycled and placed a number 7 on the bottom of the products. This can make it problematic for recyclers to separate the number 7 from the number 1 PET recycled plastic since they both produce clear products, like cups and bottles. The effects of the commingling of compostable biobased plastics and oxodegradable plastics with the recycling stream can cause processing problems for the recyclers with large variations in melt index, density, and color.[10] The manufacturing operation is careful to collect plastic with similar density, melt index, and color. Compostable plastic bags would have different colors than the clear LLDPE plastic bag and would be separated out with the other color plastic bags. However, the compostable plastic bags will have different densities and melt indexes and would cause processing problems for extrusion machines. The compostable plastic bags can be treated as a contaminant like PVC and HDPE. Contamination effects are minimized by improved sorting techniques and by regular testing of incoming materials. Automated sorting method efficiently and quickly sorts the plastic using spectroscopic techniques. Hundreds of identifications per second can help sort plastics with more than 99 percent accuracy[11] with throughput rate of 2,000 kg per hour.[12]

Experimental

The effects of contamination were evaluated by mixing biodegradable and oxodegradable plastic contaminates with the appropriate recycled plastic material, and then injection molding them into tensile and impact bars. The LDPE and HDPE post-industrial recycled plastic material was provided by Bay Polymers. Recycled plastic bag plastic, LDPE, was mixed with 10% and 20% starch-based compostable plastic bag . Also, LDPE was mixed with 10% and 20% oxodegradable plastic bag. PLA was dry mixed with recycled PET and recycled HDPE at 5% and 10% by weight concentrations. Unfortunately, injection molding of the PET was not successful due to the very high melt index of the PET. HDPE was injection molded successfully. Oxodegradable and biodegradable biobag were first cut into small pieces and then placed in an infrared oven where they softened. The plastic pieces were pressed into thin sheets and then chopped in a grinder to create a masterbatch of 100% plastic pellets. The masterbatch plastic pellets were dry-mixed with LDPE pellets and then injection molded.

The pellets were injection molded into tensile bars with an Arburg 320-A 55-ton injection-molding machine. The LDPE and HDPE tensile bars were produced with the following conditions: rear temperature of 200°C, center zone temperature of 230°C, front zone temperature of 240°C, nozzle temperature of 240°C, injection pressure of 203 MPa, pack pressure of 105 MPa, cool time of 35 seconds, injection time of 1 second, and pack time of 1 seconds. Thirty tensile-bar and impact bar samples were molded for each material with a purge of Insta-purge between each material type.

Results

The moisture was very low in all of the plastic materials. The oxodegradable plastic had the same moisture content as LDPE. PLA-HDPE and biodegradable Biobag-LDPE plastics had slightly higher moisture content than HDPE and LDPE alone. The moisture content of the plastic samples were measured with Satorius moisture analyzer. The moisture of LDPE and HDPE were less than 0.3%. LDPE with the oxodegradable plastic bag was also less than 0.3%. LDPE with the biodegradable Biobag plastic was between 0.4% and 0.8%. HDPE with PLA was between 0.3 and 0.6%. The moisture content of PET was also significantly increased with the addition of PLA. Increased moisture in PET could be deleterious.

Specific gravity was measured with an electronic density instrument, model MD-300S, from Qualitest Incorporated. The oxodegradable plastic and Biobag biodegradable plastics increased the density of the recycled LDPE plastic by 2.2% and 5.2% respectively for 20% addition of the contaminant. Table 11, also, demonstrates that PLA increased the density of recycle HDPE plastic by 5.3% with the addition of 10% contaminant. The average density of PLA straws was measured as 1.19 g/cc with a standard deviation of 0.03 g/cc.

The melt index is an indication of the viscosity of the material. [13] The melt index of the samples were measured with a LMI 4002 series melt flow indexer from Qualitest Incorporated. Plastic pellets are added to a heated chamber and flow through a tubular die as a weighted plunger moves through the top of the cylinder. The melt index, with units g/10-min, is recorded for materials based upon plastic flow during a 10-minute time interval at a prescribed temperature and mass of plunger. [14] The procedure for running the test is detailed in ASTM D-1238. The melt index test for polyethylene is run at 190°C with a 2.16 kg plunger load. The melt index was significantly changed with the addition of oxodegradable plastics to LDPE, cornstarch based biodegradable plastics to LDPE, and PLA added to HDPE. The melt index results had some inconsistencies due to the variations of the concentrations in the samples. Future research work can better evaluate the causes of the variations in melt index. The melt index of PET was also significantly increased with the addition of PLA.

The quality test results for the materials are given in Tables 1 and 2. The melt index, density, and moisture results are averaged over five samples. The results indicate that melt index is significantly affected with the addition of contaminants of oxo-degradable and biodegradable plastics. Density is moderately affected by the contaminants and moisture content is minimally affected by the presence of degradable contaminants. The contamination effects on film properties will be evaluated for haze, opacity, and dart impact. The physical appearance of the clear LDPE was dramatically affected by the addition of the oxodegradable and biobag plastic contaminants. The mixed plastic had streaks of green and other dark colors. The amount of light passing through the film was measured with an opacity meter. The contaminants reduced the opacity of LDPE and made it appear more opaque. The impact strength of the plastic film was also significantly reduced with the addition of 10% and 20% biodegradable and oxodegradable plastic contaminants. The impact strength of the plastic film was reduced 20 to 50% with the addition of the plastic contaminants. The addition of 20% oxodegradable plastic contaminant made it impossible to produce a plastic bag with LDPE due to instabilities in the bubble.

Table 1. Quality test results for LDPE with oxodegradable and bioplastic contamination.

Material	Melt Index	Density	Opacity	Thickness
		g/cc		mils
LDPE- neat	0.711	0.906	19.8	3.2
LDPE 10% oxo	0.597 (-16%)	0.911 (0.55%)	19.7	3.4
LDPE 20% oxo	0.664 (-6.6%)	0.926 (2.2%)	17.9	N/A
LDPE 10% biobag	0.646 (-9.1%)	0.929 (2.5%)	19.7	3.5
LDPE 20% biobag	0.778 (9.4%)	0.953 (5.2%)	19.5	4

Table 2. Quality test results for HDPE with oxodegradable and bioplastic contamination.

Material	Melt Index g/10 min	Density
HDPE- neat	11.07	0.945
HDPE 5% PLA	11.57 (4.5%)	0.958 (1.4%)
HDPE 10% PLA	4.154 (-62.5%)	0.995 (5.3%)

Conclusions

Compostable biobased and oxodegradable plastics reduce the quality of recycled plastics. The melt index was significantly changed with the addition of oxodegradable plastics to LDPE, cornstarch based biodegradable plastics to LDPE, and PLA added to HDPE.

References

[1] R. W. Bech, Inc., “2003 National Postconsumer Plastics Recycling Report,” American Plastics Council, <http://www.plasticsresource.com/s_plasticsresource/docs/1700/1646.pdf >(January 2005).

[2] “Biodegradable Plastics are not a Panacea to Solid Waste”, < http://www.bpiworld.org/Files/PressRelease/PRLSXOin.pdf > (April 2008)

[3] “Statewide Waste Characterization Study,” Cascadia Consulting Group, California Integrated Waste Management Board, December 2004

[4] “BPI Logo Program”, < http://www.bpiworld.org/ > (October 2005)

[5] “Biobag and the Environment”, < http://www.biogroupusa.com/mater_bi.htm > (April 2008)

[6] “A new Generation of Polymers”, < http://www.natureworksllc.com/ > (April 2008)

[7] “Mirel Products”, < http://www.metabolix.com/natures%20plastic/properties.html > (April 2008)

[8] “Bagasse Products”, < http://www.californiarecycles-store.com/index.asp? > (April 2008)

[9] “Approved Products- Resins”, < http://www.bpiworld.org/BPI-Public/Approved/3.html > (April 2008)

[10] “Plastics from plants threaten recycling,” <http://plasticredesignproject.org/PLAHome.htm > (April 2008)

[11] D. Wienke, et. al., “Adaptive resonance theory based neural network for supervised chemical pattern recognition. Part 2: Classification of postconsumer plastics by remote NIR spectroscopy using an InGaAs diode array,” *Chemometrics and Intelligent Laboratory Systems* **32** 165-176 (1996).

[12] Robert Dvorak, et. al., “Factors Influencing the Sorting Efficiency of Commingled Postconsumer Bottles using an Automated Sorting System,” SPE ANTEC Proceedings, **III** (2000).

[13] B. Nelson, “Improving the Accuracy of On-Line Melt Index Measurements,” *SPE ANTEC Papers 1998*, The Society of Plastics Engineers, May 1998, p 260

[14] J. Clay, “Melt Index from a Single Pellet,” *SPE ANTEC Papers 2001*, The Society of Plastics Engineers, May 2001, May 2001, p 47