Biodegradation of Compostable Plastics in Green Yard-Waste Compost Environment

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Abstract

Compostable plastic materials, produced from Poly Lactic Acid (PLA), corn starch, or sugar cane, degraded in a green yard-waste compost environment. The compostable plastics claim to meet ASTM D6400 standards for biodegradation, sustainable plant growth, and eco-toxicity. Biodegradation was measured by disintegration studies over 20 weeks. The commercially available compostable products, made from PLA, sugar cane, or corn starch, biodegraded while in a commercial compost facility with other common yard waste compostable items. The PLA container, cup, and knife completely degraded in 7-weeks at a rate similar to the Avicell micro-cellulose control. The cornstarch-based trash bag and sugar cane plate degraded at a similar rate as the Kraft paper control. The three materials degraded between 80% and 90% after 20 weeks.

Introduction

Plastics are seemingly ubiquitous in our world today. Plastics products are used by the consumer and then either collected for recycling or thrown away with the trash. Waste disposal companies usually collect the plastics with other recycled products. Plastics, metals, and glass are sorted from the refuse and sent to recyclers. The solid waste can be recycled or sent to an incinerator or landfill. As reported in a Statewide Waste Characterization Study, approximately 350,000 tons of rigid plastic packaging containers (RPPC) were disposed of in California during 2003 which represents approximately 1% by weight of the overall waste stream. Plastic trash bags comprised 1% and plastic film comprised 2.3% of the waste stream. [1] The commercial sector generated approximately 50% of the waste, the residential sector generated approximately 30% of the waste, and the self-hauled sector generated approximately 20% of the waste. In 2003, 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. [2] The use of biodegradable and compostable plastics in California can reduce the amount of plastics in the landfills. Composting is a promising waste management option for degradable plastics because the composting process is designed to degrade wastes. There are, however, obstacles make many communities reluctant to accept plastic bags for composting. [3] Degradable plastic bags that are effective in compost environments should break down, but also hold moisture, not be lighter than composting feedstock and begin to degrade after several days. [4]

Background

Compostable plastics degrade in composting facilities and break down into water, methane, carbon dioxide and biomass. Micro-organisms in the soil or compost degrade the polymer in ways that can be measured by standard tests over specified time-frames. Compostable plastics are defined according to the ASTM D6400 standard as materials that undergo degradation by biological processes during composting to yield carbon dioxide, water, inorganic compounds, and biomass at a rate consistent with other known compostable materials and leave no visible distinguishable or toxic residue. Biodegradable plastic is defined according to the ASTM D6400 standard as a degradable plastic in which the degradation results from the action of naturally occurring microorganisms such as bacteria, fungi, and algae. Biodegradable plastics can be made into different commercial products, including, trash bags, food containers, packaging trays, plastic utensils, and packaging containers and bags. The use of biodegradable polymers is increasing at a rate of 30% per year in some markets worldwide. [5]

Several organizations are involved in setting standards for biodegradable and compostable plastics, including, US Composting Council (USCC), American Certification System of Biodegradable Products Institute (BPI), Environment & Plastics Industry Council, American Society for Testing and Materials (ASTM), European Committee for Standardization (CEN), Japan's GreenPla program, and British Plastics Federation. The standards from these organizations have helped the industry create biodegradable and compostable products that meet the increasing worldwide demand for more environmentally friendly plastics. [6] If a biodegradable polymer does not meet the requirements listed in ASTM D6400 or EN13433, then it is not considered compostable. It must degrade in a specified time frame without leaving any residuals in the compost. [7]

Biodegradable polymers are those that are capable of undergoing decomposition into carbon dioxide, methane, water, inorganic compounds or biomass by the actions of microorganisms. The rate of decomposition, residuals, and by-products can be measured in standardized tests. Compostable polymers are those that are degradable under compositing conditions, which include actions of microorganisms, i.e., bacteria, fungi, and algae, under a mineralization rate that is compatible with the composting process. Polyethylene plastic bags that are produced with starch additives are not certified as compostable plastics since they do not meet he ASTM D6400 standards. The plastics do disintegrate but leave small plastic fragments in the compost, which violates the ASTM D 6400 standards. The ASTM D6400 standard differentiates between biodegradable and degradable plastics. Some synthetic polymers, e.g., Low Density Polyethylene (LDPE), can erode over time if blended with an additive to facilitate degradation. These polymers break down into small fragments over time but are not considered biodegradable since they do not meet the ASTM D6400 standards. Bioerodable polymers, photodegradable polymers, and water-soluble polymers break down in environments different from the biodegradable and compostable polymers and as such are outside the scope of the research.

The Biodegradable Products Institute (BPI) provides important criteria for valid full-scale testing of compostable plastics.[8] The BPI Logo Program is designed to certify and identify plastic products that will biodegrade and compost satisfactorily in actively managed compost facilities. [9] The Biodegradable Products Institute and US Composting Council (USCC) use ASTM D6400 standards to approve products for their compostable logo. The ASTM standards are the result of eight years of intensive work to identify plastic and paper products, which disintegrate and biodegrade completely and safely when composted in a municipal or commercial facility. The approved products with a compostable logo include compostable bags and film, food service items, and resins.

Experimental Work

Materials

The materials are all commercially available plastics that are made from corn, polylactic acid, potato, or sugar cane. The compostable materials that were added to compost in the laboratory experiment were representative samples of a plate made from sugar cane, a tray made from potato-starch, a trash bag made from corn starch, and a cup, fork, knife, straw, and clear clamshell container made from NatureWorks polylactic acid (PLA). The positive control materials include cellulose filter paper, Kraft paper and Avicell micro-cellulose. The micro-cellulose is also used as control in experiments in Australia and Europe. No ASTM standards exist for compost testing at commercial facilities.

The compost soil at composting facilities is active composting with thermophilic bacteria. The compost has substantial background carbon dioxide in the soil from degrading organic materials and would thus mask the degradation of the plastic sample materials making measurement of carbon dioxide produced from the degrading plastic difficult. Typically, degradation is measured by disintegration of the compostable material. A negative control, e.g., a polyethylene bag, was not used in the university compost experiment. It is well known that polyethylene bags are unaffected by soil and does not degrade in the soil over a three-month time frame. Polyethylene bags can take many years to degrade in soil and sunlight.

Experimental Set-up

The experimental set-up is similar at the CSU, Chico University Farm and the Chico municipal compost facility. The compostable products and compost were placed in a perforated plastic agricultural bag and placed in the compost mound. The temperature and moisture of the compost in the bag were measured and the ambient temperature and weather conditions were recorded. The compost mounds were turned several times a week to mix the compost. The plastic sample bags were removed from the compost before the turning operation and then were placed back in the compost after the turning. Compost maturity was measured with compost analysis kits from Solvita. The mass of the plastic samples was also recorded at weekly or bi-weekly intervals.

Compost Facilities

The city of Chico municipal compost facility is located on a 10-acre site that produces 500,000 cubic yards of compost each year via aerobic windrow compost. The compost is mixed with a large machine called a windrow turner. The turning machine straddles a windrow of approximately eight feet high by 13 feet across. Turners drive through the windrow at a slow rate of forward movement. A steel drum with paddles turns the compost rapidly. As the turner moves through the windrow, fresh air (oxygen) is injected into the compost by the drum/paddle assembly and waste gases produced by harmful bacteria are removed. The oxygen feeds the beneficial composting bacteria and thus speeds the eventual composting process. This process is then extended by windrow dynamics.[10] The facility accepts green yard waste, which includes lawn clippings, leaves, wood, sticks, weeds, and pruning. Testing in commercial compost facilities allows the compostable plastics to be exposed to active compost that should have a high degree of enzyme activity and high temperatures that mimic typical composting conditions in a traditional compost facility.

Biodegradation Results

The degradation of the compostable plastics was measured by monitoring the mass of the plastic over time. The presence of carbon dioxide and ammonia indicates the level of maturity of the compost soil. Compost maturity index was measured at weekly intervals as well as the temperature and at the compost sites. The testing in commercial compost facilities allows the compostable plastics to be exposed to active compost which should have a higher degree of enzyme activity and higher temperatures that mimic the most likely conditions that the compostable plastics will be exposed to in real life.

Disintegration can be measured by measuring the mass of the sample over time as it degrades. The bags were removed from the compost mound and the contents were screened with a 2-mm sieve to separate the compostable sample from the compost. The samples were shaken to remove the dirt and then collected and weighed. The disintegration results for the municipal compost site are listed in Table 1 for the City of Chico Municipal Compost Facility.

At the Chico Compost Facility the degradation of the compostable samples varied between compostable materials. Some of the materials were fully degraded in 7 weeks, including the Avicell microcellulose control, and the PLA knife, PLA cup, and PLA clamshell container. Thus, the PLA materials had disintegration rates comparable to the cellulose control material. The Kraft paper control had similar disintegration rates as the corn-starch based trash bag and the sugar cane plate. The three materials degraded 88%, 84%, and 78%, respectfully, after 20-weeks.

Regulated Metal Testing

The degraded materials should not leave any heavy metals in the compost soil after degradation. The compost soil was tested for lead and cadmium. The acceptable limit is 30 mg/kg for lead and 0.3 mg/kg for cadmium. The compost soil for each sample was put into solution and the heavy metal in the compost soil was measured with Fisherbrand [11] hollow cathode single-element 2 inch diameter lamps with elements for lead and cadmium. The results for cadmium were delayed because of a 7-week back-order on the lamp.

Lead and cadmium were measured by flame atomic absorption spectrometry using a Jarrell-Ash Model. Lead and cadmium absorption was measured at 283.3 nm and 228.8 nm respectively. The background correction was measured at 281.2 nm for Lead and at 226.5 nm for cadmium. The detection limits are 0.02 ppm lead and 0.005 ppm cadmium in the analytical solution. For a 1-g sample the detection limits are 0.2 ppm Pb and 0.05 ppm Cd.

The soil samples that were used during the phytoxicity testing were also used to measure the lead and cadmium levels. Approximately 10 g of compost soil from each sample was dried for 24 hours at 105 °C. The average moisture loss was about 30%. About 3 g of each sample was weighed into a 150 mL beaker to which 50 mL of 8 M HNO_3 was added. The samples were digested for 4 hours at 85 °C with occasional stirring. After 4 hours, 50 mL of deionized water was added to each sample followed by vacuum filtration through a Whatman GF/A glass filter with 1% (v/v) HNO_3. The filtrate was quantitatively transferred to a 250-mL volumetric flask and filled to the mark with 1% (v/v) HNO_3. The resulting samples all had a relatively intense orange-red appearance.

Sample preparation included adding a 0.8239 g sample of $Pb(NO_3)_2$ to a 500-mL volumetric flask, dissolved and diluted to the mark with 1% (v/v) HNO_3 yielding a 1099.5 ppm Pb^{2+} solution. Various standard solutions in the range of 0.220 to 1.10 ppm Pb^{2+} in 1% (v/v) HNO_3 were prepared along with a 1 M HNO_3 solution.

Standard solutions were prepared by dissolving 0.2460g Cd in approximately 3mL of 6M HCl and approximately 2 mL of 8M HNO3 in a 250 mL volumetric flask and diluted to the mark with 1% HCl (v/v) yield on 984 ppm Cd solution. Various standard solutions including a blank from mature compost alone were prepared from 0.0984ppm to 9.840 ppm Cd in 1% HCl.

Results

The standard solutions and eight sample solutions were analyzed using a ThermoElectron S Series Flame Atomic Absorption Spectrophotometer using an air-acetylene flame and equipped with a Pb hollow-cathode lamp detecting at 283.3 nm and a Cd hollow-cathode lamp. The sample solutions gave absorbances at or very near the lowest standard employed which was just above the detection limit of the instrument. Using 0.220 ppm Pb^{2+} as the detection limit leads to an upper limit of 20 ppm Pb^{2+} in the original soil samples. The 20 ppm value equates to 0.02 mg/kg for Pb. The Cd concentrations were lower than 1ppm which equates to 0.001 mg/kg Cd. All of the soil samples from the compostable materials had lead concentrations lower than the limit of 30 mg/kg Pb and Cd concentrations lower than the limit of 17 mg/kg Cd.

Phytotoxicity Testing

The compostable materials must not release toxic materials into the compost soil after degrading. The compost soil can be tested to assess phytoxicity, or poisonous to plants. The germination of tomato seedlings in the compost soil was evaluated after a 10-day duration. The phytotoxicity test was based upon the ISO 11269 standard. The tomato seeds are a "Tiny Tim" variety form Vaughans Seed Company. The tomato variety is one that is used in the Biology classes on campus and is known to grow quickly and is robust. The tomato seed is of a 1994 variety. 10 to 12 seeds were planted in small beverage cups (280 ml) that were filled with approximately 50 grams of compost from each of the 24-samples.

The sample containers were watered frequently while in a greenhouse. The green house was warm and moist with a temperature of 25°C and relative humidity of 80%. After 10-days in the green house with ambient light, the number and length of shoots were recorded for each sample. The lack of emerging seedlings would indicate phytotoxicity. The percentage of seeds that germinated and the average length of the seedlings are listed in Table 6. Ten seeds were placed in each container. A germination index is determined by taking the product of percent germination and the average length and dividing by 100.

All of the samples had seedlings grow except the sugar-cane samples. The test was repeated with 30 additional seeds, but no growth occurred after an additional 10 days of exposure in the greenhouse. The sugar-cane samples failed the test. The pH of the materials that supported growth ranged from 8.5 to 9.1, whereas the pH of the three samples that did not support seedling growth was between 8.2 and 8.3. Thus, the degradation of the sugar cane plates resulted in a compost soil that was slightly more acidic than the control compost soil. This might be due to the presence of acetic acid, which might be a byproduct of the fermentation of sugar. Further analysis can be done in the future as the testing is outside the scope of this research project.

Conclusions

The biodegradation results of municipal compost facility demonstrate the compostable plastics degrade in the time frame of the ASTM D6400 standards. The compostable plastics degraded within the specified time frame and left no residue in the compost soil.

The disintegration results at the municipal compost facility demonstrate that the compostable materials degrade under moist green-waste compost. The PLA container, PLA cup, and PLA knife degraded at a similar rate as the Avicel cellulose control and were degraded completely in 7-weeks. The corn starch-based Biobag trash bag and sugar cane plate degraded at a similar rate as the Kraft paper control. The three materials degraded between 80 and 90% after 20 weeks.

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Appendix

Table 1. Material Degradation Results for Compostable Samples at the Municipal Compost Facility.

		Initial 28-Jul	2 weeks	7 weeks	12 weeks	14 weeks	20 weeks
Item	Hole No	Mass, g	% degrade	% degrade	% degrade	% degrade	% degrade
Avicel cellulose control	1	28.3	29	100	100	100	100
Cup- PLA	6	13.983	28	100	100	100	100
Knife-PLA	3	3.876	48	100	100	100	100
Container PLA	4	22.642	12	100	100	100	100
Kraft Paper Control	7	20.9	28	52	69	73.4	88
Trash bag- corn starch	2	18.863	20	31	65	70.79	84
Plate-Sugar Cane	5	23.418	15	19	37	41.88	78

Table 2. Phytotoxicty of Compost Soil.

Material	Average Germination %	Average Length, mm after 10-days	Average Germination Index	Average, pH
Compost	50.00	12.33	7.43	8.73
Cellulose	46.67	8.00	3.20	8.7
Kraft Paper	30.00	9.00	3.00	8.93
Polyethylene	23.33	12.00	2.80	8.6
Trash Bag	36.67	12.00	4.40	8.93
PLA Container	26.67	8.00	2.20	8.8
Sugar Cane	0.00	0.00	0.00	8.27
PLA Cup	26.67	7.00	2.30	8.97

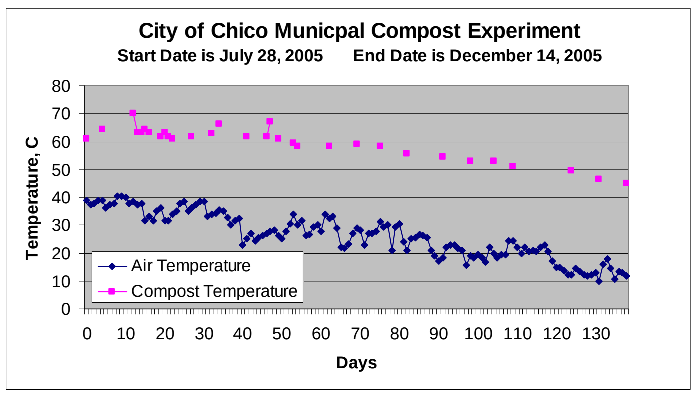

Figure 1. Temperature of the air and compost during the duration of the Municipal Compost experiment.

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