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Short Communication

Laboratory composting of extruded starch acetate and poly lactic acid blended foams ☆

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Abstract

Composting of extruded foams made of starch acetate and poly lactic acid (PLA) with pre-conditioned yard waste was studied using a laboratory composting system. Extruded foams of high amylose starch were used as the control. Degradation was measured by analyzing the exhaust gases for carbon dioxide. There were significant differences in the amounts of carbon dioxide produced in the vessels containing foams of high amylose starch and foams of starch acetate blended with 20% or 30% PLA. The high amylose starch foams completely degraded within 15 days. The starch acetate foams with 0% PLA took longer, with evolution of carbon dioxide still measurable after 55 days. The rate of degradation was faster for foams with higher PLA contents. The starch acetate foams took even longer to degrade. The maximum time was found to be 130 days for the starch acetate foams.

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1. Introduction

Increased environmental awareness has focused attention on designing materials that integrate material design concepts with ultimate disposability (Narayan, 1989, 1991, 1992). There have been increased efforts to develop biodegradable and biobased products that are ecologically and economically sustainable (Narayan, 1991, 1998; Fang and Hanna, 2001).

Efforts to replace synthetic plastics with environmentally friendly biodegradable polymers made from starch and derivatives continue. Starch can be used to make biodegradable packaging materials after hydroxypropylation of the starch (Alteieri and Lacourse, 1990) and after acetylation of starch (Shogren, 1996; Miladinov and Hanna, 1999, 2001 and Tarvainen et al., 2002). Other studies have concentrated on the production of biodegradable polymers by blending starch with other biodegradable polymers such as polylactic acid (Fang and Hanna, 2000) and Mater-Bi (Fang and Hanna, 2001).

Composting is an environmentally sound approach to transfer biodegradable waste, including the new biodegradable plastics, into useful soil amendment products. Composting is the accelerated degradation of heterogeneous organic matter by a mixed microbial population in a moist, warm, aerobic environment under controlled conditions. Biodegradation of natural materials produces valuable compost as the major product, along with water and carbon dioxide. The CO_2 produced does not contribute to an increase in greenhouse gases because it is already part of the biological carbon cycle. Composting biowastes not only provides ecologically sound waste disposal but also provides compost to maintain soil productivity and a sustainable agriculture (Narayan, 1989, 1993, 1994).

Composting of polymeric materials along with other organic waste simulates a natural recycling system (Narayan, 1989), that is, biological recycling of the polymeric

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carbon by way of the carbon cycle. Preferably, such polymeric materials are designed to be fully biodegradable using annually renewable resources (agricultural feed stocks) as the major raw material component (Narayan, 1991, 1992). Among the first "biodegradable plastics" made were blends of non-biodegradable polyolefins with starch, which were, at best, only partially biodegradable (Narayan, 1993; Gilmore et al., 1992; Barak et al., 1991; Krupp and Jewell, 1992 and Swanson et al., 1993). Those plastics were not compatible with waste management infrastructures such as composting.

With research on the utilization of starch acetate for the manufacture of biodegradable foams and plastics, it is important to know if it is biodegradable. There is no literature available on such composting studies. Miladinov and Hanna (1999, 2001) showed that the extruded starch acetate foams were water resistant and possessed optimal mechanical properties for loose fill packaging applications. This water resistant characteristic of starch acetate could pose a problem with respect to its biodegradability. Cellulose acetate, which is similar to starch acetate with regard to water resistance, is considered to be non-biodegradable. Mohanty et al. (2000) reviewed the different aspects of biodegradable polymers, highlighting the biodegradability of cellulose acetate. Bhattacharjee and Perlin (1971) and Kasulke et al. (1983) concluded that cellulose esters with DS value of less than 1.0 will degrade from microbial attack of the unsubstituted residues of the polymers and the ether linkages are generally resistant to microbial attack. Further, studies conducted by Gardner et al. (1994) proved the degradation of cellulose acetate (DS 2.2) by weight reduction and disintegration. Komarek et al. (1993) also showed that cellulose acetate (DS 1.8) degraded via aerobic biodegradation. Those studies proved that esters, with some unsubstituted groups, could be degradable by microbial attack.

Ghorpade et al. (2001) demonstrated that PLA could be composted efficiently when added in small amounts (<30% by weight) to pre-composted yard waste. PLA can be blended with starch acetate to produce foams that should be degradable. Since starch acetate with a higher DS will be more resistant to degradation, blending of starch acetate with PLA should increase the susceptibility of the blend to microbial attack. With the above aspects in mind, laboratory composting studies were conducted on starch acetate foams and blends of starch acetate and PLA foams to determine their biodegradation characteristics.

2. Methods

Hylon™ VII (70% amylose starch) was purchased from American Maize Products Co. (Hammond, IN). Talc was purchased from Barretts Minerals Technologies (New-York, NY). Denatured ethanol was purchased from Fisher Scientific, Inc., (Fair Lawn, NJ).

Starch acetate, with a degree of substitution (DS) of two, was prepared from 70% amylose cornstarch (Shogren, 1996; Miladinov and Hanna, 1999). To initiate the acetylation process, 110 kg acetic anhydride (Vopak Inc., Dallas, TX) were placed in a steam-jacketed reactor with a rotating self-wiping paddle. Subsequently, 45.5 kg of 70% amylose starch (dried at 50 °C for 48 h) were added into the reactor with 5 min of continuous mixing. Finally, 5 kg of 50% NaOH solution (Harcross Chemicals, Inc., Kansas City, KS) were added while mixing. The temperature of the reactor jacket was maintained at 123 °C. After 3 h, the reaction was stopped by rapidly adding 200 L of cold water to the reactor. The pH value of the mixture was adjusted to 5.0 by washing with water, before drying at 50 °C. When the moisture was constant at 4%, the starch was ground in a standard model No. 3 Wiley mill (Arthur H. Thomas Co., Philadelphia, PA) to pass through a 5 mm opening sieve to obtain uniform sized particles.

2.1. Samples for composting

All samples were obtained by extrusion using a laboratory co-rotating twin-screw extruder (Model CSTE-V, C. W. Brabender, Inc., Hackensack, NJ). Conical screws had diameters decreasing from 43 mm to 28 mm from the feed end to the exit end, along a length of 365 mm. Rotational speeds, for both screws, were set at 140 rpm for all extrusions. The barrel temperature for the feed zone was set to 50 °C. The other two barrel sections and the die were varied according to the starch samples used. Extrusions were carried out maintaining full feed, ensuring that flights and feed port were full throughout the extrusion runs. Extrudates were collected when the system stabilized as indicated by constant back pressure at the die, constant torque and constant output flow rate.

Blends of unmodified high amylose starch and acetylated starch (DS 2) with 0%, 10%, 20% and 30% PLA were extruded. The high amylose starch samples were extruded with 22% moisture content, on a dry basis, with an extruder barrel temperature of 140 °C and a 3 mm diameter extruder die nozzle. All starch acetate samples were extruded with 12% ethanol content, extruder barrel temperature of 150 °C and 4 mm die nozzle diameter. These conditions were selected based on previous experiments to obtain the best expanded foams for the respective starches. The samples were obtained by extrusion and collected when the system was stable. Samples were stored in airtight containers.

2.2. Composting

Composting was assessed using ASTM Standard Test Method D 5338-98 (2000) for determining aerobic biodegradation of plastic materials under controlled composting conditions. The composting setup used was as described in Ghorpade et al. (2001) with a total of six composting vessels. Biodegradability was measured as the percentage of the carbon from the test material that was mineralized to CO_2 during the test period. During the test, humidified air was supplied continuously to the test vessels containing the samples in a mature compost inoculum. The amounts of

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