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Biodeterioration of Mater-Bi Y Class in Compost with Sewage Sludge

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Abstract

This paper presents results of biodeterioration of Mater-Bi YI01U under natural weather conditions in compost with sewage sludge. The tests were performed at a waste treatment plant and - for comparison - under laboratory conditions at stable temperature.

The compost pile was prepared outdoors at a waste treatment plant and consisted of active sludge, burnt lime /CaO/ (to ravage pathogenic bacterium and eggs of parasites) and straw.

The characteristic parameters of compost, such a dry mass of compost, pH of compost and activity of dehydrogenases were determined.

Changes in weight and morphology of Mater-Bi YI01U samples were tested during the experiment.

The obtained weight loss results were compared with that from Weight Loss Under Controlled Composting Condition test method, which simulates the biodegradation behaviour of a material under composting conditions. According to this test method, Mater-Bi Y Class lost more than 90% of weight after 4 months when disposed of in the standard environment under controlled conditions, but in the investigated natural, weather-dependent, composting conditions this material lost about 20% of weight after the same time of incubation.

Keywords: starch, cellulose, Mater Bi, biodeterioration, sewage sludge

Introduction

Environmental problems concerning polymers arise from the heaping of hardly degradable plastic materials in the environment. Polymers cause serious problems in disposal. Demand of polymeric materials for the 21st century is directed towards environmentally degradable plastics, especially in the packaging field. Environmental and economic concerns are stimulating research in the development of new materials for packaging. Particularly attractive are the new materials based on natural renewable resources, preventing further impact on the environment. One of the solutions to reduce these problems is making natural polymers, which are environmentally friendly. Cellulose is one of these polymers, which has been used in many applications [1]. Starch is an inexpensive abundant product available annually from corn and other crops. It is totally biodegradable in a wide variety of environments and allows the development of totally degradable products for specific market needs [2, 3]. Starch can be destructurized and compatibilized with different synthetic polymers to satisfy a broad spectrum of market needs. Destructurized starch behaves as a thermoplastic polymer and can be processed as a traditional

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plastic. When alone, however, its sensitivity to humidity makes it unsuitable for most of the applications. Since natural polymers such as starch and cellulose are biodegradable, renewable, low cost, have low densities and are environmentally friendly composites of these natural polymers offer a new class of materials which can provide environmental protection.

Mater-Bi products are thermoplastic materials based on starch, developed and marketed by Novamont S.p.A. Italy. They are a new generation of bioplastics from natural sources which retain their properties while in use and, when disposed of properly, are completely biodegrade. It is known that living microorganisms transform Mater-Bi products into water, carbon dioxide and/or methane [4].

The biodegradability of Mater-Bi has been measured by Novamont S.p.A. under composting conditions on the laboratory scale using a method originally set up at Organic Waste System (Gent, Belgium). The Organic Waste System method is based on the determination of CO_2 evolved by the test material when mixed with mature compost, which acts as a solid substrate as an inoculum rich in thermophilic microorganisms, and as a source of nutrients. The test material-compost mixture is kept at a high temperature under aerobic conditions, at a proper level of humidity [4, 5].

This method has been adopted by the American Society of Testing and Materials as the "ASTM Standard Test Method for Determining Aerobic Biodegradation of Plastic Materials Under Controlled Composting Conditions" (ASTM D-5338-92).

However, in real composting the test material is embedded in a fresh the organic waste rather than in mature, stabilized compost as in the Organic Waste System method. But a fresh organic waste would be unsuitable for the ASTM D-5338-92 test because it would produce too high a CO_2 background, masking the CO_2 evolved by the test material. To clarify this point another test was thus suggested by Tosin et al. [6]. They evaluated the biodegradation of Mater-Bi following its weight loss in a fresh synthetic waste composed mainly of rabbit feed and sawdust [6].

Tosin procedure was also applied by Novamont S.p.A. and proved to be very practical, cheap, and effective. This procedure can be used mainly as a screening method to provide fast but reliable results - very useful for laboratories involved in biodegradable materials development [6].

However, there is still a need to recognize the biodegradability of Mater-Bi materials under weather-dependant conditions including compost, farm soil, paddy soil, river, lake and sea water, where after utilization they are often annihilated.

Thus the aim of this paper is to estimate biodeterioration of Mater-Bi YI01U in compost with sewage sludge under outdoor conditions and the comparison of obtained results with that from Weight Loss Under Controlled Composting Conditions [4, 6]. In this way we would like to check how extend sewage sludge can be used for plastic utilization in the future.

Material and Methods

Material

Mater-Bi Grade YI01U made of thermoplastic starch and cellulose derivatives from natural origin was supplied by Novamont S.P.A. The samples were in sheet form (7 x 8cm) and were cut into 1.7 x 8 cm rectangles with 1mm thickness. Average weight of each sample was ~1.8g±1mg.

Environments

The incubation of Mater-Bi Y Class took place in the compost with sewage sludge under outdoor conditions and - for comparison - in laboratory at a stable temperature.

The compost used in this work was formed with sewage sludge from the waste treatment plant in Gdynia. The compost pile 1.5 x 2 x 1m (width, length and height) consisting of sewage sludge, burnt lime /CaO/ and straw, was stored outdoors at the waste treatment plant. Burnt lime (0.45kgCaO/1kg dry mass of compost) was added to ravage pathogenic bacterium and egg-parasites and to deacidificate active sludge and convert dehydrated active sludge to compost. The straw was added to maintain higher temperature and slack structure in the all-compost pile [7].

The compost pile was not aerial, so we could expect that the kind of living microorganisms in this compost pile prepared under natural conditions are dependent on pile location. Aerobic (upper part of pile), microaerophilic (in the middle) and facultative anaerobic (at the bottom) conditions existed [8].

The samples of Mater-Bi Y Class were put into a special large perforated basket filled with inoculum and buried 1m into the compost pile.

The laboratory inoculum consisted of only sewage sludge and the same amount of burnt lime. The laboratory inoculum was located in a closed polypropylene container 0.5 x 0.5 x 0.75m (width, length and height) and incubated at room temperature. Then we could suppose that in the laboratory inoculum there existed rather microaerophilic conditions.

Methods

1. Investigation of compost

- *Dry mass in compost* was determined based on drying the samples at 105°C until a constant weight was obtained [9]. Moisture content was then calculated.
- *Activity of dehydrogenases* was measured by spectrophotometric method with TTC (triphenyltetrazolium chloride). This is the method for an estimation of biochemical activity of microorganisms in sewage sludge by oxidation process of organic compounds. This method is based on the dehydrogenation of glucose added to the compost and transfer of hydrogen to the colourless biological active compound of TTC, which

Table 1. Parameters of compost with sewage sludge under natural and laboratory conditions.

Months	Parameters							
	Temp. [^{0}C]		pH		Moisture content [%]		Activity of dehydrogenases [mol/mg d.m.]	
	a	b	a	b	a	b	a	b
August	28.6	22.1	7.46	7.38	61.7	46.8	0.064	0.055
September	19.2	22.1	7.84	7.69	59.7	49.1	0.044	0.055
October	15.1	17.6	7.09	7.09	40.5	39.9	0.039	0.048
December	5.2	15.8	6.8	6.8	43.7	45.6	0.042	0.045
February	4.1	12.9	6.49	6.8	51.9	54.2	0.058	0.030
April	11.1	18.1	5.65	5.42	45.0	64.3	0.018	0.022
May	16.3	18.5	6.75	5.92	48.5	56.2	0.040	0.038

a - compost with sewage sludge under natural conditions; b - inoculum with sewage sludge in laboratory

undergoes a reduction to TF ($TTCH_2$, red compound). The intensity of this colour is measured using a "Specol" colorimeter (490nm) [9].

- *pH of compost* was determined using a pH-meter. 50 g of compost and 100 cm^3 of distilled water were homogenized for 30 min. and incubated for 1 hour at room temperature. Then the pH of the solution was determined using a Teleko pH-meter N 5172 f. [9].

2. Investigation of Mater-Bi Y Class samples

After incubation, the samples were removed from the environment and washed with distilled water and dried at room temperature to a constant weight.

- *Weight changes (%)* were determined using an electronic balance Gibertini E 42s. Clear and dried samples of Mater Bi after biodegradation were compared with samples before biodegradation.
- *Microscopic observations of polymer surface changes* were performed at a magnification of 1:300 with reflected microscope of Polish Optical Company linked to a computer through a camera using the Software VidPres program. The surface was analyzed before and after biodegradation.

Results and Discussion

It is known that the parameters of the environment such as temperature, pH, and moisture content have a significant influence on development of living microorganisms in the natural environment.

The characteristic parameters in outdoor and laboratory compost were measured during the experiment and are presented in Table 1.

Taking the conditions of environments into consideration we can expect that the microaerophilic conditions resulting from the activity of living organisms were at the end of the composting process.

Activity of dehydrogenases indicated that the variety of microorganisms which produced enzymes were involved in biodegradation process. Looking at the parameters presented in Table 1 we could notice that at the beginning of the experiment (August) in natural compost at the waste treatment plant temperature, moisture content (depending on weather conditions) and activity of dehydrogenases were higher than in the laboratory inoculum. But during the next months the temperature and activity of dehydrogenases were higher in the laboratory test. The activity of dehydrogenases in natural compost depended on the degree of the growing microorganisms of the populations. The level of activity of dehydrogenases in the laboratory was decreasing slowly because the conditions stimulated a decrease in the amount of live microorgan-

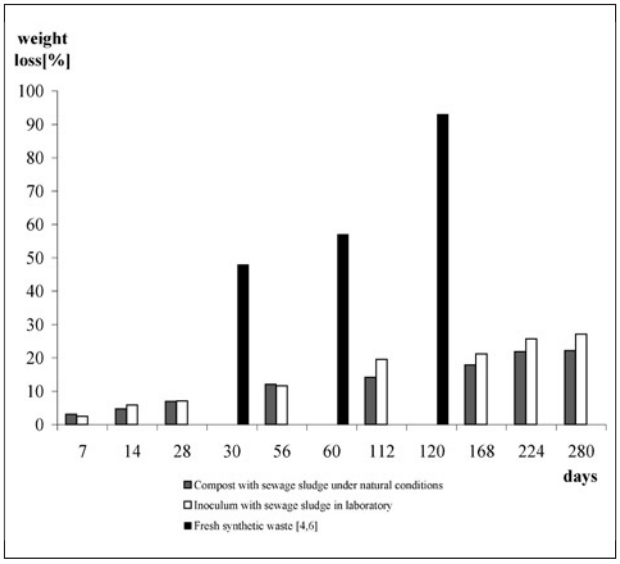

Fig. 1. The weight losses of Mater-Bi Y Class [%] after degradation in different environments.

isms. The pH of compost under natural and laboratory conditions was at a similar level. With a decrease of moisture content we could observe the lower absolute value of activity of dehydrogenases. This was evidence that the psychrotrophic and psychrophilic microorganisms played the main role in the biodegradation process.

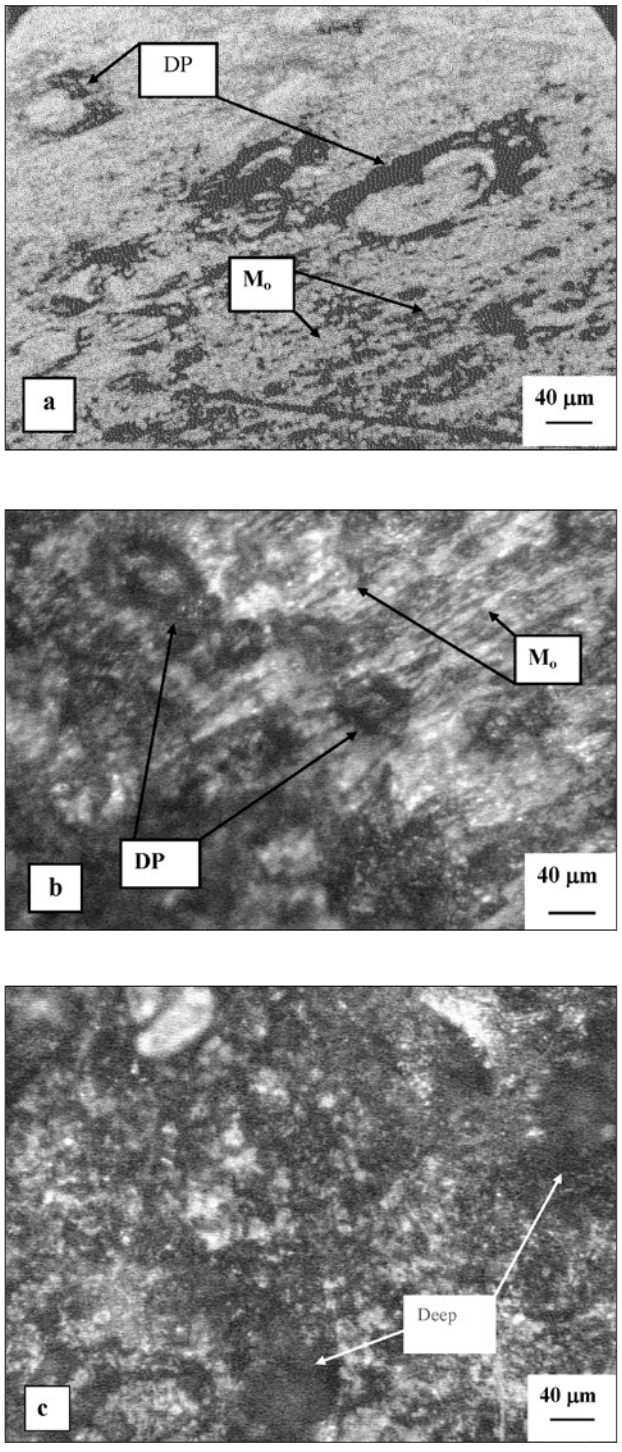

Fig. 2. The image of Mater Bi Y class under reflected light microscope before (a) and after (b, c) incubation in outdoor compost conditions: b, yellow part of the sample, c, grey part of the sample.

The weight losses of Mater-Bi samples expressed as a percentage of initial weight after the incubation in compost with sewage sludge under natural and laboratory conditions are presented in Fig. 1. There are also results obtained from Weight Loss Under Controlled Composting Conditions. In this test method Mater-Bi was mixed with fresh synthetic waste. According to this test with fresh synthetic waste the biodegradation time of Mater-Bi Y Class is about 4 months (weight loss ~93%) [4, 6].

The decreases of weight of Mater-Bi samples were also observed during the degradation time in compost with sewage sludge and in laboratory inoculum. The weight loss of samples incubated in the natural environment after 1 week was slightly higher (Fig. 1) than in laboratory conditions. But in the next weeks in the natural environment (compost at sewage farm) the changes were smaller than in the laboratory, which could be because of the higher activity of dehydrogenases in the laboratory inoculum than in outdoor compost.

Generally the rate of biodegradability of Mater-Bi Y Class was very low in compost with sewage sludge under natural weather conditions. After 4 months of incubation in compost with sewage sludge the weight losses of Mater-Bi Y Class had reached ~20%.

When we compared the weight losses of Mater-Bi samples obtained from the test under natural conditions and laboratory inoculum with the results obtained from Weight Loss Under Controlled Composting Conditions test method the visible and distinct differences in the weight losses of Mater-Bi Y Class were observed. It was caused by different conditions and a different kind of living microorganism in the standard fresh synthetic waste test method (50^0C, almost alkaline pH, thermophilic microorganisms) and in our experiment (lower temperature - changing from 4.1^0C to 28^0C, slightly acid pH and psychrotrophic and psychrophilic microorganisms). The marked differences between results obtained with these two methods indicate that the sewage sludge composting process under natural conditions is not sufficiently microbially active for biodegradation of starch-cellulose material.

The experiment in compost with sewage sludge (natural and laboratory inoculum) has lasted for 12 months (~30% of weight loss) and continues.

After incubation in compost the surfaces of the samples studied are changed. The changes were different in various places. Visually they lost the glossy appearance and colour and became partially grey and partially yellow. After 40 weeks of incubation in the natural environment the grey part occupied 50% of the surface sample, while in samples incubated in laboratory inoculum the grey part was about 75% of the surface.

The samples of Mater Bi Y class were also observed under a reflected microscope linked to the computer through a camera. The images of the surfaces before and after incubation in outdoor compost conditions with sewage sludge from waste treatment plants are shown in Fig. 2.

The matrix (starch) and the dispersed phase (cellulose) are easily visible in the surface observed under

reflected microscope (Fig.2a). Both the matrix (M_o) and the dispersed phase (DP) are partially oriented in the same direction, probably as a result of processing. In those places, where the orientation of the matrix is visible (M_o), a high contrast of level differences in the surface is present. The orientation of the matrix is even more visible in the yellow parts of the samples (less changed visually) after incubation in outdoor compost conditions (Fig. 2b). Moreover, the decrease in contrast between level differences and more particles of dispersed phase are observed. These observations suggest the beginning of degradation in the matrix rather than in the dispersed phase. In the most visually changed places (gray ones) the image is obscure but the wholes and the loss of orientation can be recognized due to the progress of degradation (Fig. 2c).

Changes in the surface of the samples treated in laboratory inoculum and observed under microscope are similar to those found in the samples incubated in natural compost. In slightly changed places the orientation of the sample is still visible. In those places where degradation proceeds to a higher extent, the surface of the samples incubated in laboratory compost is rough and it is difficult to register a reasonable image. However, greater level differences are present than in the samples incubated in outdoor compost, which informs us about deeper surface degradation in the samples incubated in laboratory inoculum.

Conclusion

The results of the experiment show that biodeterioration of Mater-Bi Y Class in compost with sewage sludge under outdoor conditions takes a longer time than in a fresh synthetic waste in the standard compost, applied by Novamont S.p.A. The outdoor conditions slow down the rate of biodegradation of Mater-Bi. Nevertheless, this type of environment (compost with sewage sludge from waste treatment plant) cannot be excluded as an environment for biodegradation of plastics provided that we accept the longer procedure of degradation.

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