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Original Research

Biodegradation of Starch-Based Films in Conditions of Nonindustrial Composting

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Abstract

Our study tested the susceptibility of biodegradable films to degradation in non-industrial composting conditions. The qualitative and quantitative changes in the films studied were shown by the tests of strength, weight loss, and microscopic images.

After about 9 weeks of composting, many hollows and pits appeared in the surface of the foils studied and their mechanical parameters were significantly decreased, which proved the loss of biodegradable components.

Keywords: biodegradation, composting, plastic packaging, starch

Introduction

Continuously increasing amounts of municipal waste has forced humanity to face up the burning problem of waste disposal with minimal environmental load. One of the promising solutions to this problem is the industrial application of biological waste treatment methods, well-known for centuries [1]. The requirements of the contemporary market are forcing the packaging industry to constantly seek new solutions that will meet the needs of customers. On the other hand, environmental considerations need to be taken into account while maintaining economic parameters within reasonable limits. Unfortunately, most of the commonly used packaging materials are not susceptible to biodegradation. Hence much effort has been taken within the so-called eco-design to develop new materials and increase the market share of biodegradable polymers in packaging. There is no doubt that biodegradable polymers are unable to replace the plastics of petrochemical origin [2] in many applications; however, they can be successfully applied, bringing considerable benefits to the environment [3].

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The process of polymer biodegradation is affected by many factors that can be roughly grouped as follows and can vary widely.

1) The properties of polymer: chemical composition, type of functional groups, molecular mass, internal structure, content of additives, contaminants, etc. [4].
2) The environment in which the process takes place: temperature, illumination, humidity, mechanical and chemical impact (pH, available oxygen, the presence of other compounds, etc.).

In real conditions the process of biodegradation takes place in the environment where a large variety of microorganisms is present [5]. As far as municipal waste is concerned, the raw waste composition and the set of microorganisms present in each batch is unique, impossible to reproduce in laboratory. Because of this specificity, the terms 'biodegradation' and 'biodegradability' are not absolute attributes of a given material but are closely related to the specific conditions in the environment in which the process is to occur [6]. Thus, in addition to studies using standardized laboratory methods, it is necessary to conduct studies of biodegradation process in real conditions [7]. In many cases biodegradable packaging waste ends up in backyard composters or municipal composting plants where conditions are significantly different from those achieved in industrial plants and laboratories [8]. The problem of degradation of biodegradable plastics in environmental conditions arouses increasing interest, thereby forcing new studies on the behaviour of many materials in different environments [9, 10].

The idea behind the presented research was to see how the process of biodegradation of selected packaging materials already in common use (commercially available), proceeds in the actual conditions of municipal composting plants.

Materials and Methods

Experimental subjects were five types of films based on corn or potato starch available on the European market (Table 1). The degradation process was carried out in a composting plant in the area of Poznan in the prism of mature compost, exposed to atmospheric conditions. The process was conducted during 61 consecutive summer days.

Five sets of different type films in the form of sheets of 210 × 300 mm ≈ A4 in size (Fig. 1) were placed in a compost heap prepared in advance. Then, they were covered with another layer of compost so that the distance between the samples and the edge of the pile was not less than 25 cm. During the experiment, the temperature inside the heap ranged between 22 and 32ºC. The conditions that occurred in the compost heap differed significantly from those in the industrial installations. However, they were the actual conditions in a real composting plant where the study was conducted. Moreover, the conditions were also similar to those prevailing in the home composter of one of the authors (V ≈ 1m^3, at 25 and 37ºC, humidity 30-40%), where typical household wastes are processed. It can be assumed that in everyday life it is highly likely to meet multiple situations in which the materials tested will be composted in conditions similar to those specified in this study.

Subsequent sets of samples were removed from the heap after 7, 14, 20, 34, and 61 days. Parameters characterizing the compost on a given sampling day are included in Table 2.

The resulting samples were pre-cleaned using a soft bristle brush.

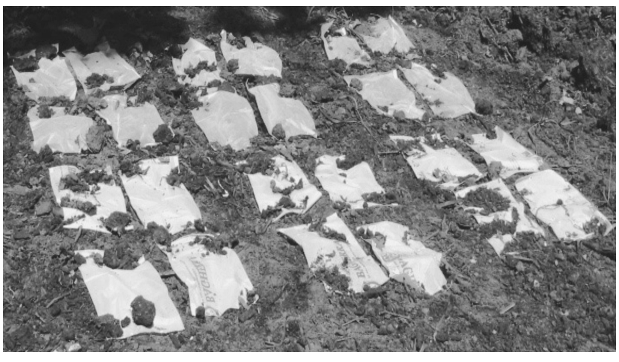

Fig. 1. The arrangement of samples (one of two layers) in the compost heap.

Table 1. Characterization of the films investigated.

Property	S1	S2	S3	S4	S5
Thickness [mm]	26	51	23	23	100
Basis weight [g/m^2]	36	63	27	26	130

Source: the specification of the material supplied by the manufacturer.

Table 2. Compost parameters.

Composting time [days]	Humidity [%]	Dry matter [%]
0	34.7±0.6	54.1±1.3
7	29.6±4.4	58.6±3.3
14	28.5±2.7	58.6±3.3
20	26.8±2.3	63.0±2.3
34	25.0±1.5	65.6±3.7
61	22.2±1.7	64.8±3.7

n = 10

All film samples were characterized in terms of visual evaluation, mechanical properties, SEM photos.

Visual Evaluation

Photographs were taken at each of the predetermined sampling times using a digital camera. They were arranged in chronological order to visually evaluate the film degradation over time.

Mechanical Properties

The tensile properties of the films tested (tensile strength and elongation at break) were measured until the total loss of film's mechanical properties. The study was conducted on an INSTRON 5655 testing machine. Samples were prepared in accordance with PN-EN ISO 527:3-1998: sample width – 15 mm, length of the working section 50 mm, jaw feed rate 200 mm/min.

SEM Photos

Changes in the structure of films were observed using images from a scanning electron microscope Philips SEM model 515, magnification 5000X, voltage 24V.

Results and Discussion

In the samples removed consecutively from the heap, the visual symptoms of biodegradation were visible.

As soon as after a week the film surface became dull with numerous discolorations and sporadic cracks and breaks. The samples gathered in the second week of the experiment bore evident traces of disintegration of the

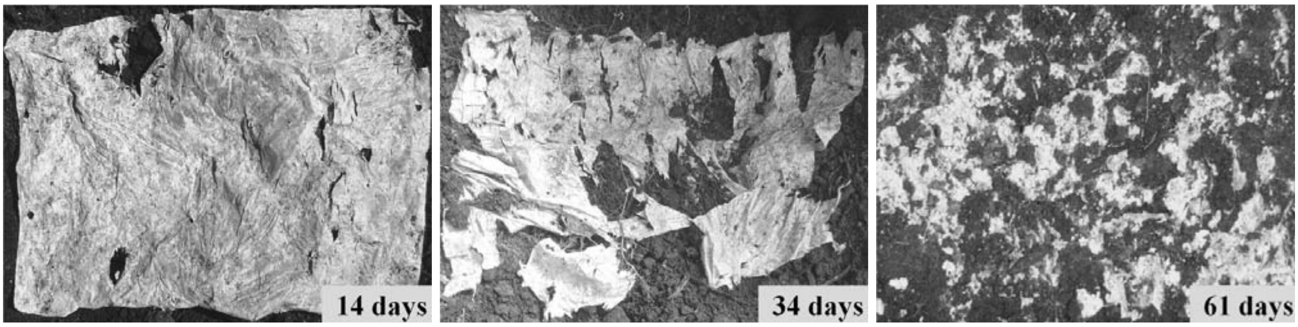

Fig. 2. The course of degradation of samples S1 – after 14, 34, and 61 days of composting.

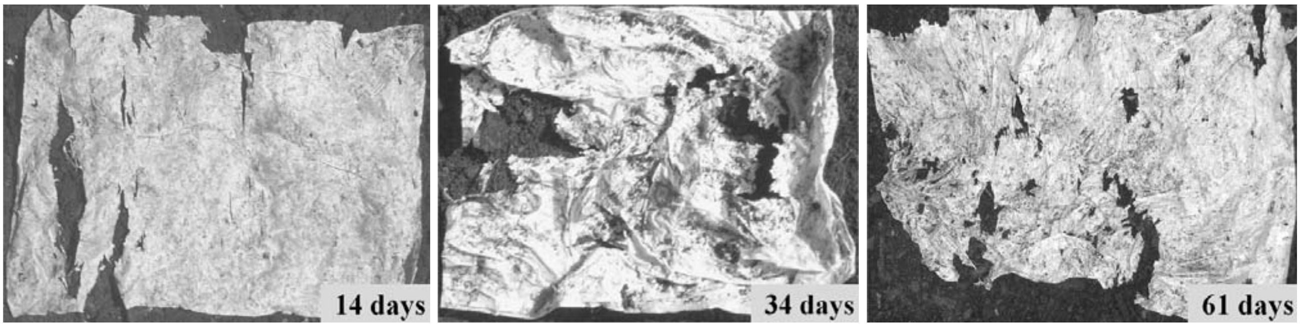

Fig. 3. The course of degradation of samples S3 – after 14, 34, and 61 days of composting.

structure in the form of many tears, cracks, and discolorations (Figs. 2 and 3).

The samples collected on subsequent dates wore enhanced signs of disintegration. For the samples stored in compost for over two weeks, the extraction of the test sheet in one part, in most cases, was impossible. Disintegration of sample S5 ran much faster – just after a week it was impossible to collect the test sheet in one piece. The rate of this sample decomposition was estimated as two- three times higher than those of the other samples. The state of samples S1 and S3 after two months was similar to that of sample S5 after one month of composting (Figs. 2-4).

The samples collected from the compost in the first three weeks of the tests were subjected to careful purification and drying (40ºC, 2 hrs.). Whenever possible, rectangular pieces were cut from the samples intended for determination of mass change. Because of varying sizes of the preserved parts of the sheets, the results' objectification was performed by conversion of the sample mass and size into basis weight. The mass losses are given in Table 3.

As expected, significant loss of mass was recorded, increasing with the composting time. Taking into account small sample batches and the fact that only the best preserved samples were assessed, the data obtained should be considered as estimations.

In no way does this diminishes the significance of the results as they indicate a trend that could provide the basis for future, more advanced research. The relatively high rate of biodegradation in the first phase of the process – the disintegration of material – is a characteristic feature of many biodegradable materials.

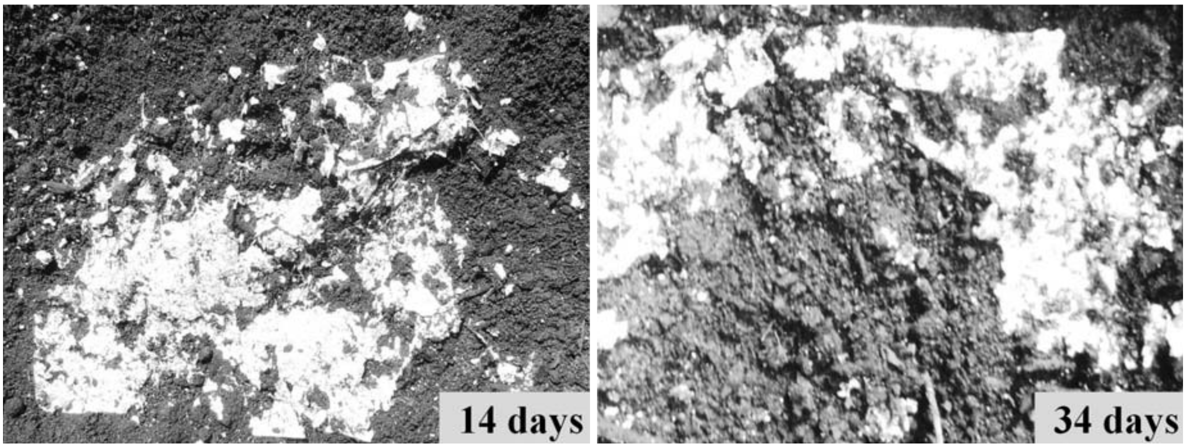

Fig. 4. The course of degradation of samples S5 – after 14 and 34 days of composting.

Table 3. Mass loss of samples during composting [%].

Composting time [days]	S1	S2	S3	S4
7	-5.3	2.7	-1.2	-1.6
14	-13.1	-12.2	-0.4	-2.4
20	-18.2	-21.5	-8.8	-29.7

Despite the fact that in the mild conditions of the experiment conducted in open air compost heap, the process of biodegradation was slower than in the laboratory [11]. From the practical point of view of the industrial composting process, the result is satisfactory.

Fig. 5 shows the electron-microscopic photographs of samples illustrating structural changes in their surfaces. SEM images confirm the ongoing process of bio-disintegration.

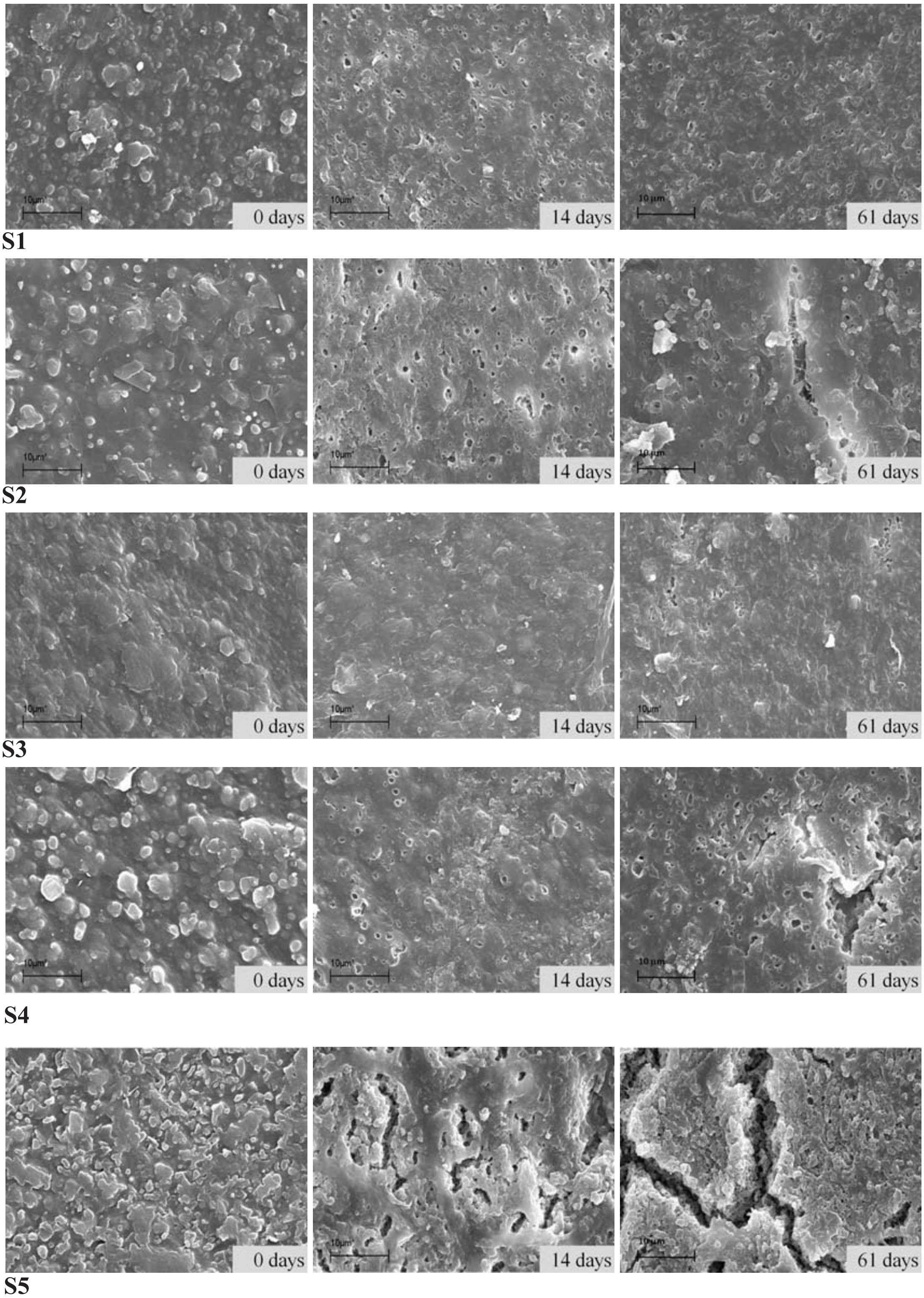

Fig. 5. SEM images of the samples of tested materials after 0, 14, and 61 days of composting.

Table 4. Tensile strength [MPa].

Material	Testing direction*	Composting time [days]			Change** [%] 7/14 days
		0	7	14	
S1	MD	17.0±2.1	16.8±1.8	-	1/-
	TD	8.3±1.4	4.7±2.6	-	43/-
S2	MD	18.2±2.0	13.8 ±0.9	-	24/-
	TD	13.7±1.4	2.6±0.9	-	81/-
S3	MD	20.1±3.4	14.7±2.0	10.8±1.4	30/46
	TD	14.7±2.9	10.8±0.6	7.7±2.3	27/48
S4	MD	17.9±2.8	11.5±2.7	5.8±4.4	36/61
	TD	17.9±2.5	8.2±1.3	2.0±0.8	54/89

*MD – machine direction, TD – transverse direction
**Sample not subjected to composting = 100%
$n = 7$

Table 5. Elongation at break [%].

Material	Testing direction*	Composting time [days]			Change** [%] 7/14 days
		0	7	14	
S1	MD	51±23	19±4	-	63/-
	TD	9±1	20±9	-----	-20/-
S2	MD	289±25	23±5	-	92/-
	TD	512±60	19±4	-----	81/-
S3	MD	236±58	196±61	51±21	17/78
	TD	355±104	101±37	28±11	72/92
S4	MD	490±85	107±55	38±38	78/94
	TD	188±34	43±8	16±4	77/91

*MD – machine direction, TD – transverse direction
**Sample not subjected to composting = 100%
$n = 7$

Before the composting process, the structure of films had no visible holes and cavities – only irregular particles of starch are visible. After 2 weeks of composting the surfaces of the samples became dull and porous, with numerous holes and cavities. With increasing composting time, the number of holes or crevices and the size of material loss also increased.

It should be noted that for the preparation of samples (spraying a layer of gold) for further SEM analysis, only the best-preserved pieces of research material, characterized by the lowest degree of disintegration, were selected.

In addition to macro-and microscopic changes in the polymer structure, the progressive degradation of the material also was evident from a drastic reduction in the mechanical parameters. When possible, the tensile strength and elongation at break were measured.

Due to the rapid progressive disintegration of the films, the preparation of a sufficient number of samples – film strips – was only possible for samples remaining in the compost for one or two weeks. As expected, the value of tensile strength decreased with increasing time of composting (Table 4), while for S3 and S4 films the determination was also possible after two weeks. Comparison of changes in the parameter studied showed that the rate of the process for both films was identical. The ratio of relative change after 7 days to the same parameter and after 14 days for both materials in both directions was approximately 0.6.

Drastic weakening of the strength in the initial stage of composting causes further disintegration of the composted material upon mixing and sifting the compost heap, which fosters distribution of the resulting pieces throughout the whole volume of the heap, and thus intensifies the further process of composting.

The processes in the compost heap the films were subjected to, led to a drastic reduction in elasticity of the samples tested (Table 5). The observed effect is consistent with the observations of other authors that microorganisms first attack amorphous areas of the polymer that are mainly responsible for the elasticity of the material.

Conclusions

The results obtained from the experiment conducted clearly show that the process of biodegradation of the studied starch-based films (corn or potato) runs at a substantial rate, even in the compost heap significantly different from the adopted standard conditions used in the industrial installations of biological waste treatment.

As follows from the resulting degree of decomposition of the materials studied, taking into account the conditions under which it was achieved, even in backyard home composters where the conditions are usually milder and less stable than in the industrial installations, effective distribution of starch-based packaging materials is possible.

Acknowledgements

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References

1. LUSK P. Methane Recovery from Animal Manures: A Current Opportunities Casebook. 3rd Edition. NREL/SR-25145. Golden, CO: National Renewable Energy Laboratory. Work performer by Resource Development Associates, Washington, DC., **1998**.
2. SIRACUSA V., ROCCULI P., ROMANI S., ROSA M.D., Biodegradable polymers for food packaging: a review. Trends Food Sci. Tech., **19**, 634, **2008**.
3. LEJA K., LEWANDOWICZ G. Polymer Biodegradation and Biodegradable Polymers – a Review. Pol. J. Environ. Stud. **19**, (2), 255, **2010**.
4. ARTHAM T., DOBLE M., Biodegradation of aliphatic and aromatic polycarbonates. Macromol Biosci, **8**, (1), 14, **2008**.
5. ZHAO J.H., WANG X.Q., ZENG J., YANG G., SHI F.H., YAN Q. Biodegradation of poly(butylene succinate) in compost, J. Appl. Polym. Sci., **97**, (6), 2273, **2005**.
6. KRZAN A., HEMJINDA S., MIERTUS S., CORTI A., CHIELLINI E. Standardization and certification in the area of environmentally degradable plastics. Polym. Degrad. Stabil. **91**, (12), 2819, **2006**.
7. KALE G., AURAS R., SINGH S. P., NARAYAN R. Biodegradability of Polylactide bottles in real and simulated composting conditions. Polym. Test. **26**, 1049, **2007**.
8. DAVIS G., SONG J.H. Biodegradable packaging based on raw materials from crops and their impact on waste management. Ind. Crop. Prod., **23**, 147, **2006**.
9. RUTKOWSKA M., KRASOWSKA K., HEINOWSKA A., STEINKA I. JANIK H., HAPONIUK J., KARLSSON S. Biodegradation of Modified Poly(ε-caprolactone) in Different Environments. Pol. J. Environ. Stud. **11**, (4), 413, **2002**.
10. DOMKA L., MALICKA A., JAGŁA K., KOZAK A. Biodegradation of Starch-Modified Foil in Natural Conditions. Pol. J. Environ. Stud., **18**, (2), 191, **2009**.
11. OHTAKI A., NAKASAKI K. Ultimate degradability of various kind of biodegradable plastic under controlled composting conditions. Waste Manage. Res. **18**, 184, **2000**.