Original Research

Biodegradation of Starch-Modified Foil in Natural Conditions

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Abstract

The biodegraded foils based on starch and containing different fillers to improve the foil properties have been studied. The foil resistance to solvents of different character, their susceptibility to biodegradation in compost and in the soil, in natural conditions, have been determined. The foil quality and rate of their degradation have been observed under an electron microscope (SEM images).

Keywords: biodegradable polymers, fillers, packaging industry, natural environment

Introduction

Plastics make a group of materials of increasing contribution on the market. For the last decade the technology of plastic production has considerably changed thanks to the use of different type fillers. Thus obtained composites have improved the properties of plastics and extended the range of their use so that the natural materials have been gradually phased out. Their increasing use has been accompanied by the increasing pollution of the natural environment with hardly degradable waste (underground and surface waters, soil, dumping grounds) [1]. Recycling is only a partial solution, so attempts have been made to improve the degradability of plastics in natural conditions [2]. The biodegradable materials are produced on the basis of biodegradable polymers obtained from reproducing raw materials, such as starch, or from petrochemical materials. Such polymers can be used separately or in combination with resins or other additions. The structural base of starch-based plastics produced on an industrial scale is the natural monomer or natural fibres of cellulose or lignin. The material is reinforced by vegetable proteins added in 5-10% of dry mass, coming from corn [3,4]. Plastics based on starch are called second generation. They have become very popular in the packaging industry (produced in the form of foils, thermosetting trays and containers, disposable cups), the cosmetics industry, sports and logistics [5-8].

We have obtained biodegradable foils based on starch, glycerine and a filler. The materials have been tested as to the rate and character of their degradability in natural conditions in compost and in the soil. The resistance of the foils to different solvents has also been tested. The texture of the foils at different stages of degradation is presented in the SEM photographs. The influence of the types of filler and plasticizer on the properties of the foils and the rate of their degradation have also been analyzed.

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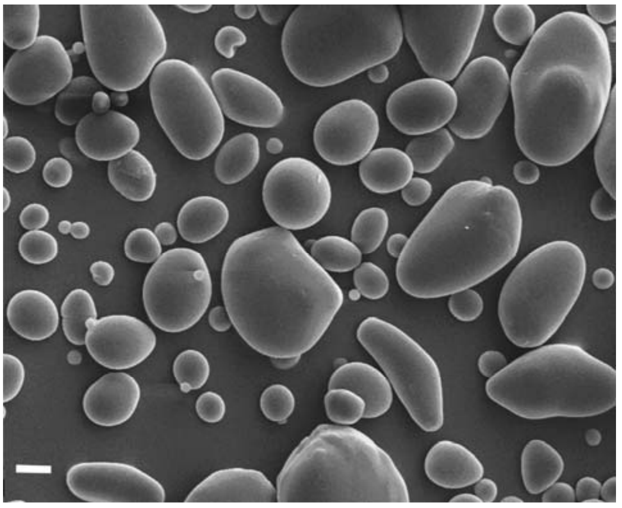

Fig. 1. Photo of starch used in the study.

Fig. 2. The compost in which the samples studied were embedded (foil composed of starch, glycerine and montmorillonite after 23 days of biodegradation).

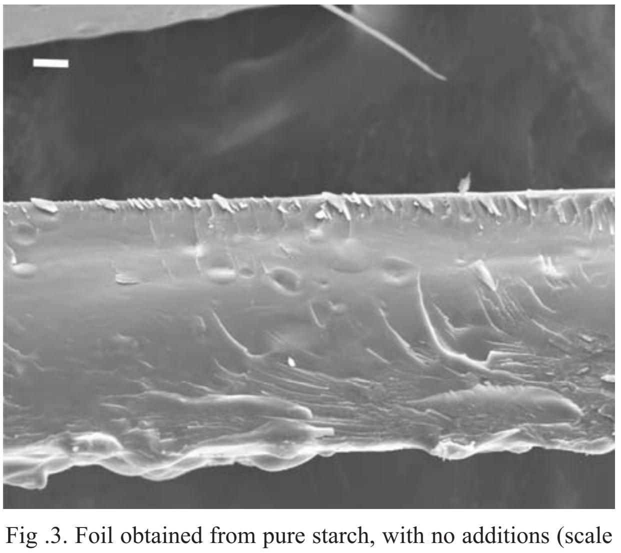

Fig .3. Foil obtained from pure starch, with no additions (scale bar 20 μm).

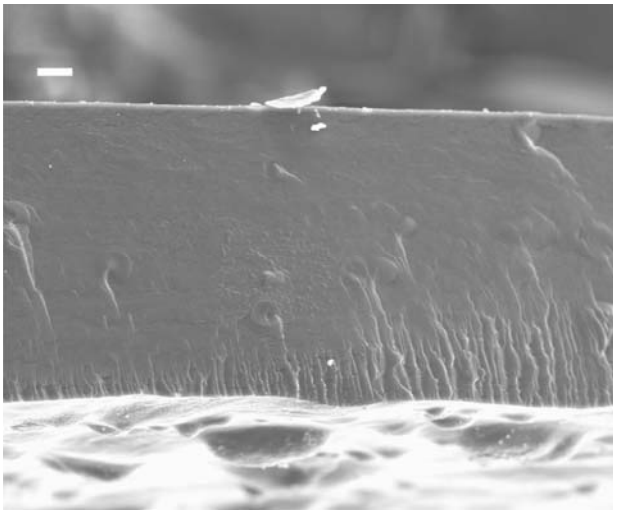

Fig. 4. Foil obtained of starch and glycerine as a plasticizer (scale bar 20 μm).

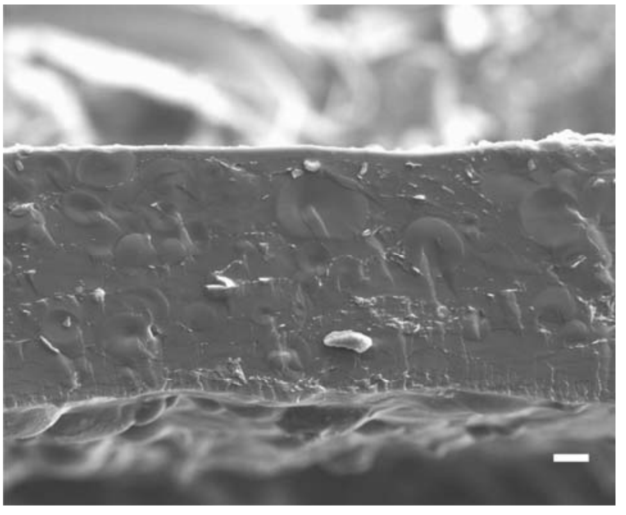

Fig. 5. Foil obtained of starch foil and glycerine as a plasticiser and kaolin as a filler (scale bar 20 μm).

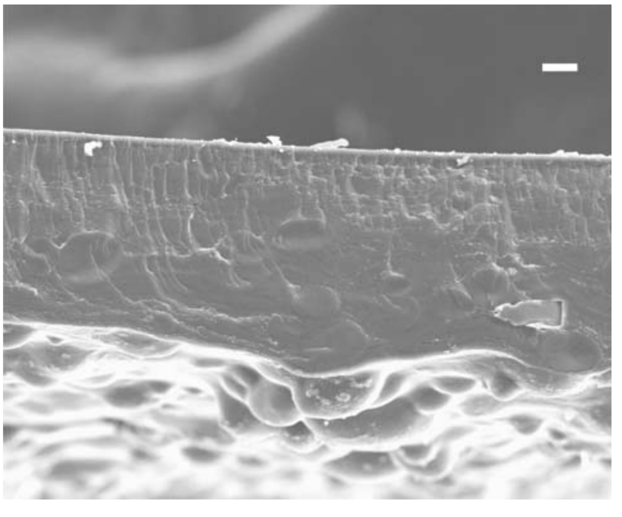

Fig. 6. Foil obtained of starch foil and glycerine as a plasticiser and montmorillonite as a filler (scale bar 20 μm).

Material and Methods

The starch used was purchased from the Potato Processing Plant "TRZEMESZNO" Ltd. The starch was SUPERIOR STANDARD, with smell and taste typical of potato starch, with no foreign smell or taste, of purely white colour, not darker than reference standard I, in the form of homogenous powder with no agglomerations or agglutinations (Fig. 1).

To improve the properties of the plastics obtained, the effects of the following fillers have been tested: kaolin, bentonite, montmorillonite.

The plastic foils of the following compositions have been studied:

1. Starch foil with no additions (pure starch).
2. Starch foil with glycerine as a plasticizer (starch + glycerine).

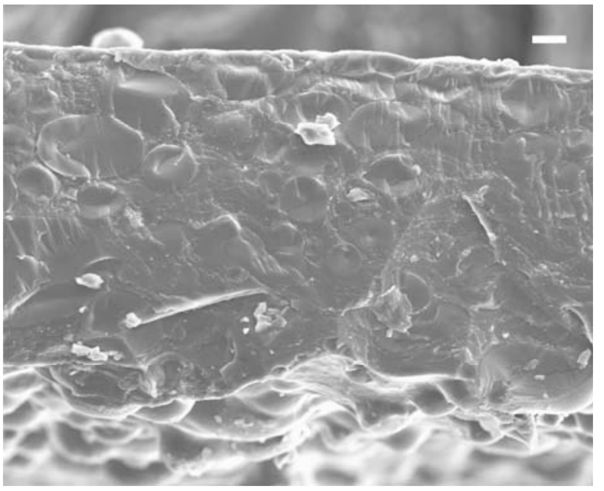

Fig. 7. Foil obtained of starch foil and glycerine as a plasticizer and bentonite as a filler (scale bar 20 μm).

Table 1. Resistance to selected solvents.

Type of foil	Water	Chloric acid (HCl)	Sodium hydroxide (NaOH)	Acetone	Methanol
Pure starch	insoluble	soluble	insoluble	insoluble	insoluble
Starch +glycerine	insoluble	soluble	insoluble	insoluble	insoluble
Starch+glycerine + kaolin	insoluble	soluble	insoluble	insoluble	insoluble
Starch +glycerine + montmorillonite	insoluble	soluble	insoluble	insoluble	insoluble
Starch +glycerine + bentonite	insoluble	soluble	insoluble	insoluble	insoluble

Table 2. Characterization of biodegradation in the compost.

Type of foil	Mass of foil sample prior to degradation [g]	Mass of foil sample after biodegradation [g]
Pure starch	0.8993	Total degradation after 17 days
Pure starch	1.1093	Total degradation after 21 days
Pure starch	0.3000	Total degradation after 14 days
Starch +glycerine	3.5761	Total degradation after 35 days
Starch +glycerine	0.7246	Total degradation after 25 days
Starch +glycerine	0.9370	Total degradation after 30 days
Starch + glycerine + kaolin	0.9793	Total degradation after 28 days
Starch + glycerine + kaolin	1.7159	Total degradation after 40 days
Starch + glycerine + kaolin	1.5150	Total degradation after 34 days
Starch + glycerine + montmorillonite	2.2288	Total degradation after 39 days
Starch + glycerine + montmorillonite	2.5527	Total degradation after 42 days
Starch + glycerine + montmorillonite	3.0906	Total degradation after 46 days
Starch + glycerine + bentonite	0.6692	Total degradation after 34 days
Starch + glycerine + bentonite	0.7933	Total degradation after 36 days
Starch + glycerine + bentonite	2.3445	Total degradation after 46 days

Table 3. Characterization of biodegradation in the soil.

Type of foil	Mass of foil sample prior to biodegradation [g]	Mass of foil sample after biodegradation [g]
Pure starch	2.9405	Total decomposition after 29 days
Pure starch	1.6137	Total decomposition after 20 days
Pure starch	0.2898	Total decomposition after 15 days
Starch + glycerine	4.2904	3.9321
Starch + glycerine	3.4061	2.9510
Starch + glycerine	0.3669	0.2849
Starch + glycerine + kaolin	1.7069	1.3432
Starch + glycerine + kaolin	3.4165	2.9764
Starch + glycerine + kaolin	1.1501	0.8762
Starch + glycerine + montmorillonite	1.5746	1.3681
Starch + glycerine + montmorillonite	3.8284	3.6820
Starch + glycerine + montmorillonite	2.3385	2.1869
Starch + glycerine + bentonite	1.5406	1.1743
Starch + glycerine + bentonite	3.3834	2.9450
Starch + glycerine + bentonite	1.4370	0.9251

3. Starch foil with glycerine as a plasticizer and kaolin as a filler (starch + glycerine + kaolin).
4. Starch foil with glycerine as a plasticizer and montmorillonite as a filler (starch + glycerine + montmorillonite).
5. Starch foil with glycerine as a plasticizer and bentonite as a filler (starch + glycerine + bentonite).

To determine the resistance of the foils to solvents they were placed in water, chloric acid, sodium hydroxide, methanol and acetone.

The character and rate of biodegradation of the foils were studied in natural conditions.

- In a compost made of leaves and cooking waste (vegetable and fruit waste). The compost was placed on a special wooden platform ensuring air access. Prior to placement in the compost the foils were weighed and labelled to facilitate their identification. The temperature and pH of the compost were controlled; pH varied from 7.98 to 8.65, and temperature varied from 0.5ºC to 8.5ºC, depending on the temperature of the surroundings.
- In the soil. The process of biodegradation in garden soil lasted for 40 days. The temperature and pH of the soil were regularly controlled. The pH value was close to 7.20, while the temperature varied from 2ºC to 11ºC. Prior to insertion in the ground the foil samples were weighed and labelled. The progress in the process of biodegradation is illustrated by Fig. 2.

The SEM photographs were taken at magnification that varied from 250x to 5000x on a scanning electron microscope Zeiss EVO-40 at the voltage of 19 kV. The SEM photographs are displayed with the scale in μm to give an idea of the size of the particles.

Results and Discussion

Figs. 3-7 present the cross-sections of the starch-modified foils with and without the addition of a plasticizer and filler. Analysis of the SEM images indicates that after the addition of a plasticiser the surface of the foil gets smoother, while the addition of the filler makes the surface more uniform. The foil with the addition of bentonite has uneven surface. Tables 1-3 present the data characterizing an foil resistance to solvents and to the process of biodegradation in the compost and in the soil.

Depending on their composition, the starch-based foils were found to show different elasticity and tensile strength as well as the process of their biodegradation was characterized by different rates.

The pure starch foil with no plasticiser or filler is brittle and undergoes degradation is the shortest time, both in the compost and in the soil.

The foil with glycerine as a plasticiser (starch + glycerine) has a greater tensile strength, is more elastic and relatively quickly undergoes degradation (but slower than pure starch foil).

The foils with glycerine as a plasticiser and kaolin, montmorillonite or bentonite as a filler are more elastic and have greater tensile strength than the above-two types of foil. The foil with bentonite as a filler is the least elastic of the three foils with fillers and its degradation in the natural conditions is the fastest of the three.

All foils are resistant to water, sodium hydroxide, acetone and methanol and undergo degradation in chloric acid.

After embedding in the compost or in the soil, the foils got softened and the process of their degradation started. They were kept in the compost or in the soil till completion of the biodegradation process. The process was longer for the foil samples embedded in the soil and more effective in the compost (Tables 1, 2). The biodegradation was the slowest for the sample of starch, glycerine and montmorillonite.

As shown in the SEM photographs (Figs. 3-7), after the addition of glycerine the surface of the foil became smoother. After the introduction of the mineral filler, the foil surface became uneven but uniform. The surface of the foil with bentonite was the most uneven and for this foil incoherence was observed over the cross-section. The montmorillonite tactoids are dispersed in the polymer matrix. Similar patterns were observed for biodegradable polyester/montmorillonite nanocomposites [9].

Conclusions

The results of the study have shown that the starch-based foils with the plasticizer (glycerine) and the filler (kaolin and montmorillonite) are characterized by greater elasticity than those of pure starch. The foils studied are resistant to water, sodium hydroxide, methanol and acetone. Their tensile strength values are high enough to permit their use in the packaging industry. In the natural conditions they undergo biodegradation already after 30 days to 43 days, depending on the composition. The process of biodegradation in the compost is more effective than in the soil and more effective at higher temperatures.

The properties of the foils studied make them suitable for use in the packaging industry. Their fast biodegradation in natural conditions is their great advantage.

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