Original Research

Biodegradation of Degradable/Biodegradable Plastic Material in Controlled Composting Environment

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Abstract

The biodegradability of different plastic material was investigated under aerobic conditions. The samples were placed in the compost pile and were checked over 15 weeks. After the expiration of the experimental period it was found that the samples with the additive (samples 1, 2, and 3) had not decomposed, their color had not changed, and that no degradation or physical changes had occurred. SEM photomicrograph images of the surface of the samples confirm this statement. Samples 4, 5, 6, and 7 (certified as compostable) were decomposed. Samples 5, 6, and 7 exhibited the highest decomposition rates. The SEM observation showed that the film surface of the samples was totally eroded and its smoothness disappeared. The present study suggests that the biodegradable characteristics differed significantly depending on the type of biodegradable/degradable plastics.

Keywords: biodegradation, degradability, degradable/biodegradable plastics, composting, waste

Introduction

Synthetic polymers are recognized as major solid waste environmental pollutants. Many synthetic polymers, resistant to chemical and physical degradation, are produced and utilized. They present disposal problems when their usefulness ceases. For plastic wastes, an alternative method of disposal is biodegradation [1]. Biodegradation concerns specially designed so-called biodegradable polymers [2]. Increasing amounts of synthetic polymers produced results in increasing interest in polymer biodegradation. The recent incorporation of biological waste treatment (i.e., composting and biogasification) in an integrated approach to solid waste management has resulted in a growing commercial interest in the development of biodegradable materials for consumer products [1, 3]. On the market are a number of materials known as biodegradable plastics (i.e., starch-based materials, cellulose-derived polymers, bacterial polyesters, and a range of synthetic polymers). Biodegradable plastics can decompose into carbon dioxide, methane, water, inorganic compounds, or biomass via microbial activities within the natural environment [4]. Biodegradable plastics are designed to degrade under environmental conditions or in municipal and industrial biological waste treatment facilities [5]. However, the main problem associated with designing biodegradable polymers is the optimization of their chemical, physical, and/or mechanical properties, as well as their biodegradability [1].

Biodegradation of plastics depends on both the environment in which they are placed and the chemical nature of the polymer. Biodegradation is an enzymatic reaction; hence it is very specific to the chemical structures and bonds of the polymer. There are different mechanisms of polymer biodegradation. The process of polymer biodegradation is

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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.
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.) [6].

In real conditions the process of biodegradation takes place in the environment, where a large variety of microorganisms is present. As far as municipal waste is concerned, the raw waste composition and the set of microorganisms present in each batch is unique and impossible to reproduce in a 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. Thus, in addition to studies using standardized laboratory methods, it is necessary to conduct studies of the biodegradation process in real conditions [6]. 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 [6]. The problem of degradation of biodegradable plastics in environmental conditions arouses increasing interest, thereby forcing new studies on the behavior of many materials in different environments [7-11].

It is clearly important to study the impact of these biodegradable/degradable materials on waste management so as to realize the truth benefit and the need to establish adequate waste management systems and legislation. In the present study, degradability of commercial biodegradable/degradable materials advertised as 100%-degradable or certified as compostable within actual conditions of a municipal composting plant were investigated.

Materials and Methods

The research of biodegradability was carried out in real conditions in the Central Composting Plant in Brno, Czech Republic. The process was conducted during 15 consecutive summer weeks. Experimental subjects were seven types of single-use plastic bags commercially available on the European market, advertised as 100%-degradable (sample 1,2,3) or certified as compostable (sample 4, 5, 6, 7). The material composition of samples is presented in Table 1.

Table 1. Material composition of samples.

Sample	Type	Description
1	N/A*	BIO-D Plast
2	HDPE+TDPA	100% degradable
3	N/A	100% degradable
4	Starch	Compostable 7P0147
5	Starch and Plycaprolactone	OK Kompost AIB VINCOTTE
6	N/A	Compostable 7P0202
7	Natural material	Compostable 7P0073

The eighth, control sample was cellulose filtering paper. This last sample was to check the potential of biological decomposition in the tested environment.

The experiment started in May 2012. All experimental samples were inserted into one clamp within the compost pile. The samples were installed at a height of 1 m from the upper side of the compost pile and at 1.5 m from the lower side of the pile (Fig. 1). Dimensions of the clamp into which the compost pile was placed were 6×36 m and its height was ca. 2.5 m. In these conditions, the experimental period was estimated to be 15 weeks. During the experiment, the temperature inside the heap ranged between 60 and 68ºC.

The experiment ended in mid-September 2012. After the end of the experiment, the samples were lifted from the compost pile and pre-cleaned using a soft bristle brush. Experimental samples were subsequently photographed and assessed. Samples were characterized in terms of visual evaluation, and SEM photos.

Fig. 1. Placing the samples into a composting pile.

Visual Evaluation

The samples were properly marked and photographs were taken using a digital camera to document visual comparison. The results of visual evaluation are in detail described in "Repeated research of biodegradability of plastics materials in real composting conditions" [11].

SEM Photos

An ancillary technique within monitoring the biodegradation of polymeric materials is scan electron microscopy (SEM). This technique allows monitoring of changes in the morphology of materials at the micro scale. In order to realize such monitoring, the SEM was

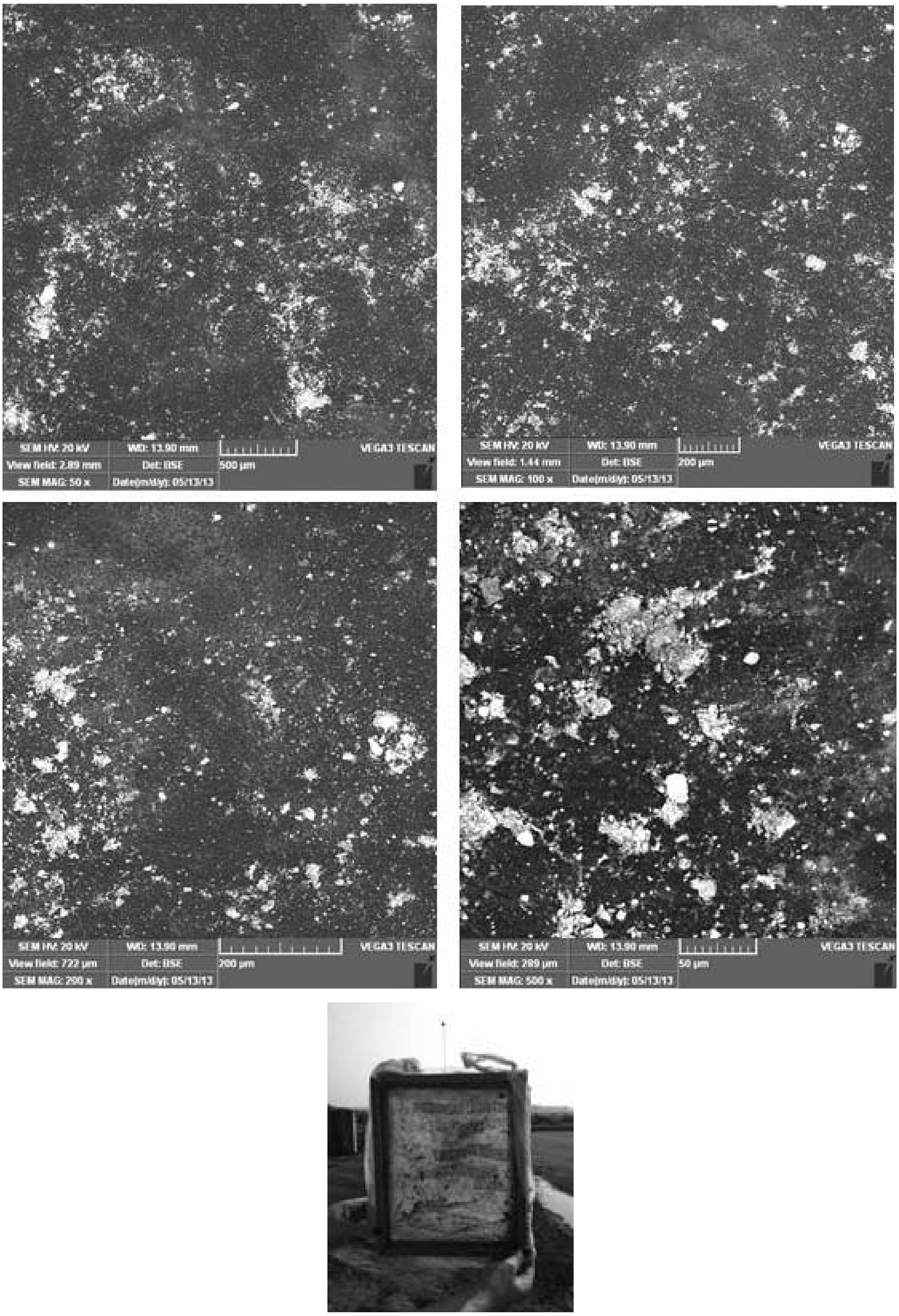

Fig. 2. Sample 1 (50×, 100×, 200×, 500×, real).

used. Changes in the structure of films were observed using images from a VEGA3 scanning electron microscope.

Results and Discussion

Following visual evaluation of the investigated samples, they were subsequently subjected to scanning electron microscopy on the VEGA3 device. It concerned the images of the assessed samples that had undergone the process of composting (15 weeks). Samples were viewed at 50×, 200×, 500×, and 1000× (samples 6 and 7) magnification, and some samples (sample 5) were magnified by 2000× μm. Magnification was chosen for detailed detection of disruption of researched materials. With samples that showed no changes at lower magnification, higher magnification was not undertaken.

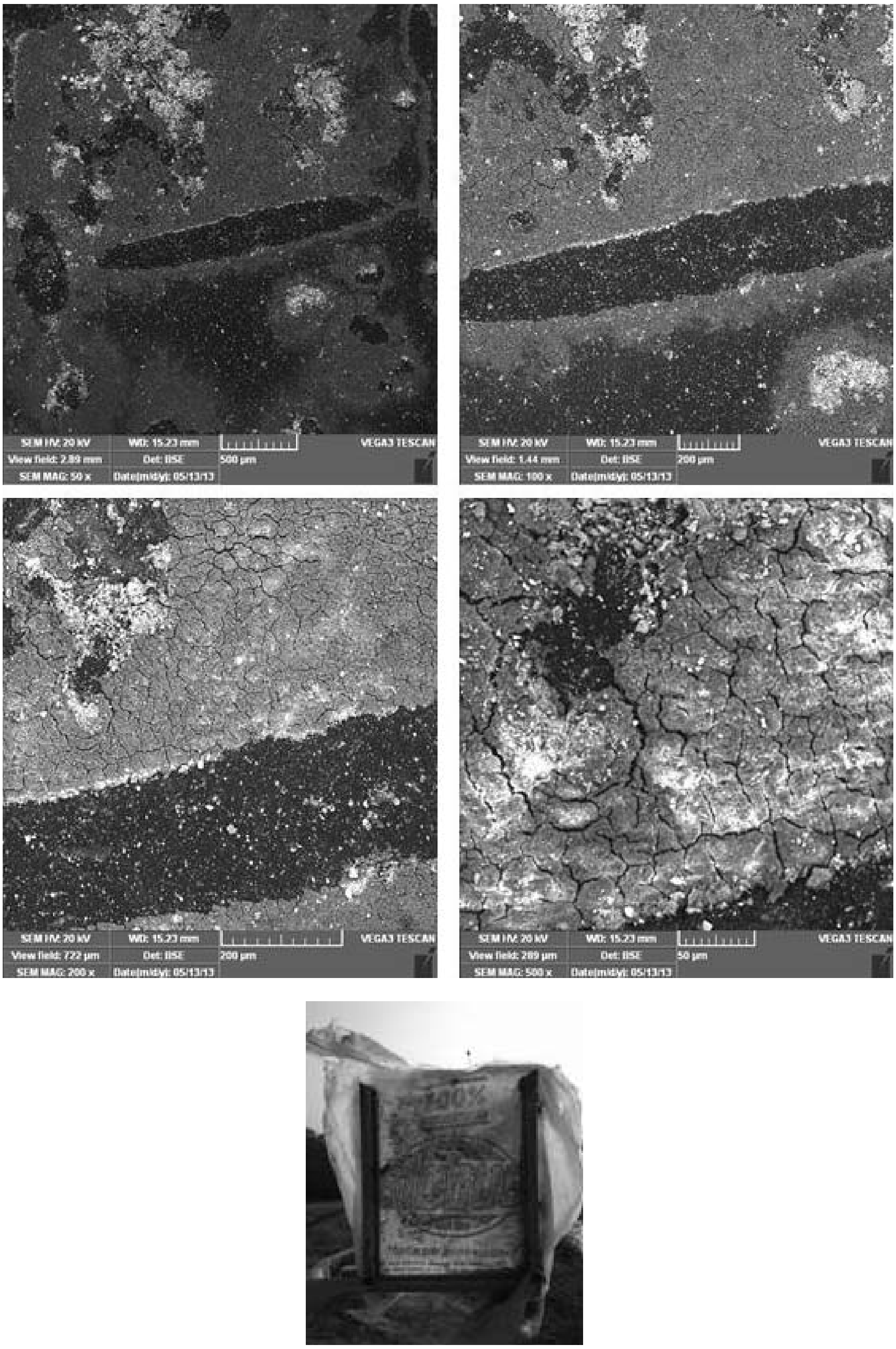

Fig. 3. Sample 2 (50×, 100×, 200×, 500×, real).

Photographs of samples that have undergone the process of composting in the Compost Pile of Central Composting Plant in Brno, Czech Republic, and images from the electron microscope at different magnifications are shown in Figs. 2-8. The value of magnification is cited in each picture.

Fig. 2 shows images of sample 1 and a photo of the sample after the termination of the composting process. As the image shows, the surface structure of the material does not display changes (deterioration of the surface) at any picture. The surface is smooth, with no visible pinholes. Sample 1 showed neither decomposition nor degradation.

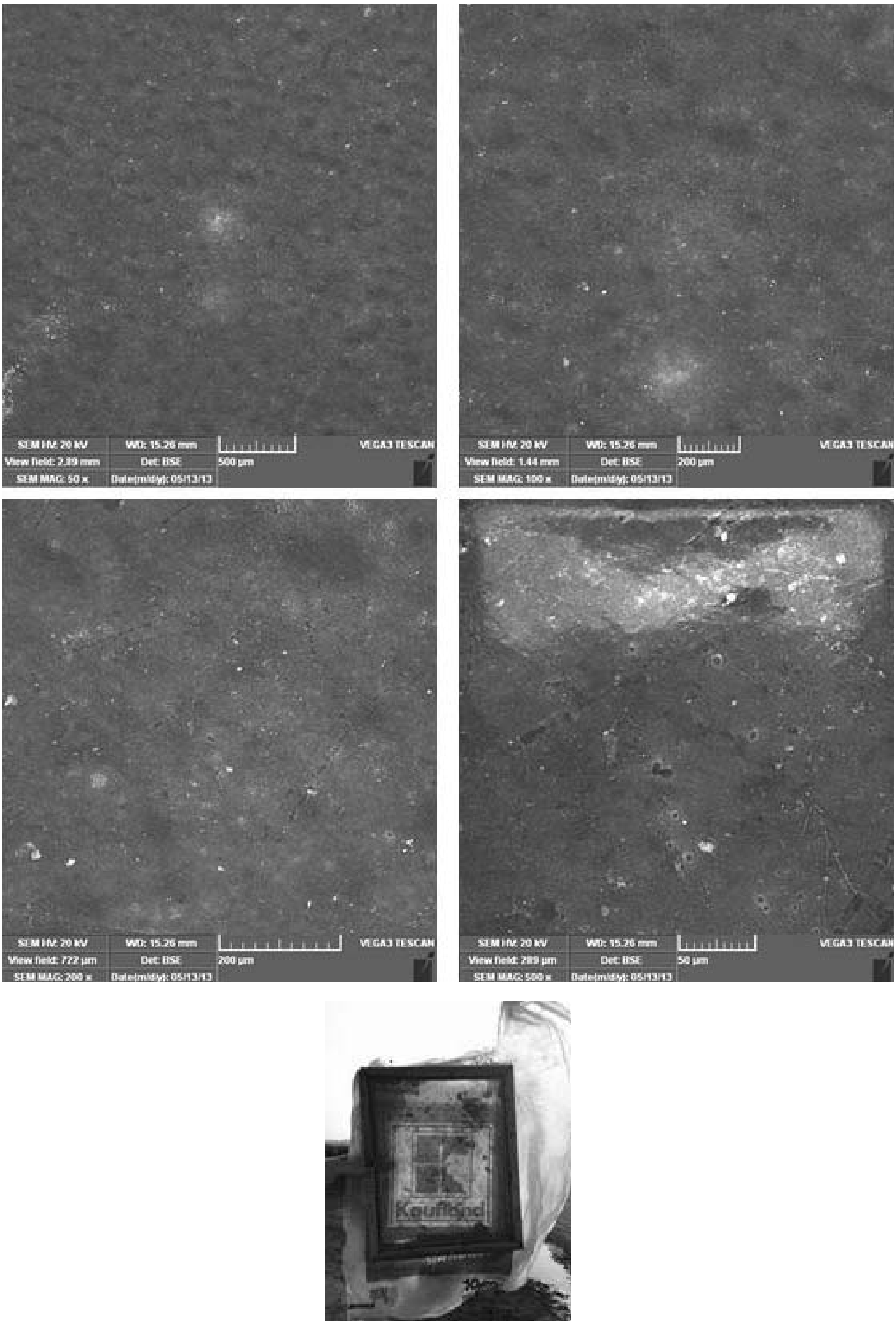

Fig. 4. Sample 3 (50×, 100×, 200×, 500×, real).

Sample 1 showed 0% degradation at the end of the composting process.

Fig. 3 shows images of sample 2 and a photo of the sample after the termination of the composting process. The structure of the surface is relatively smooth, thus at the highest resolution it shows cracks. During the "naked eye" visual inspection sample 2 showed 0% degradation at the end of the composting process; the material was still firm without visible modifications.

Fig. 4 shows images of sample 3 and a photo of the sample after terminating the composting process. The structure of the surface is smooth, without any visible modifications (cracks, holes). During visual assessment sample 3 showed 0% degradation at the end of the composting

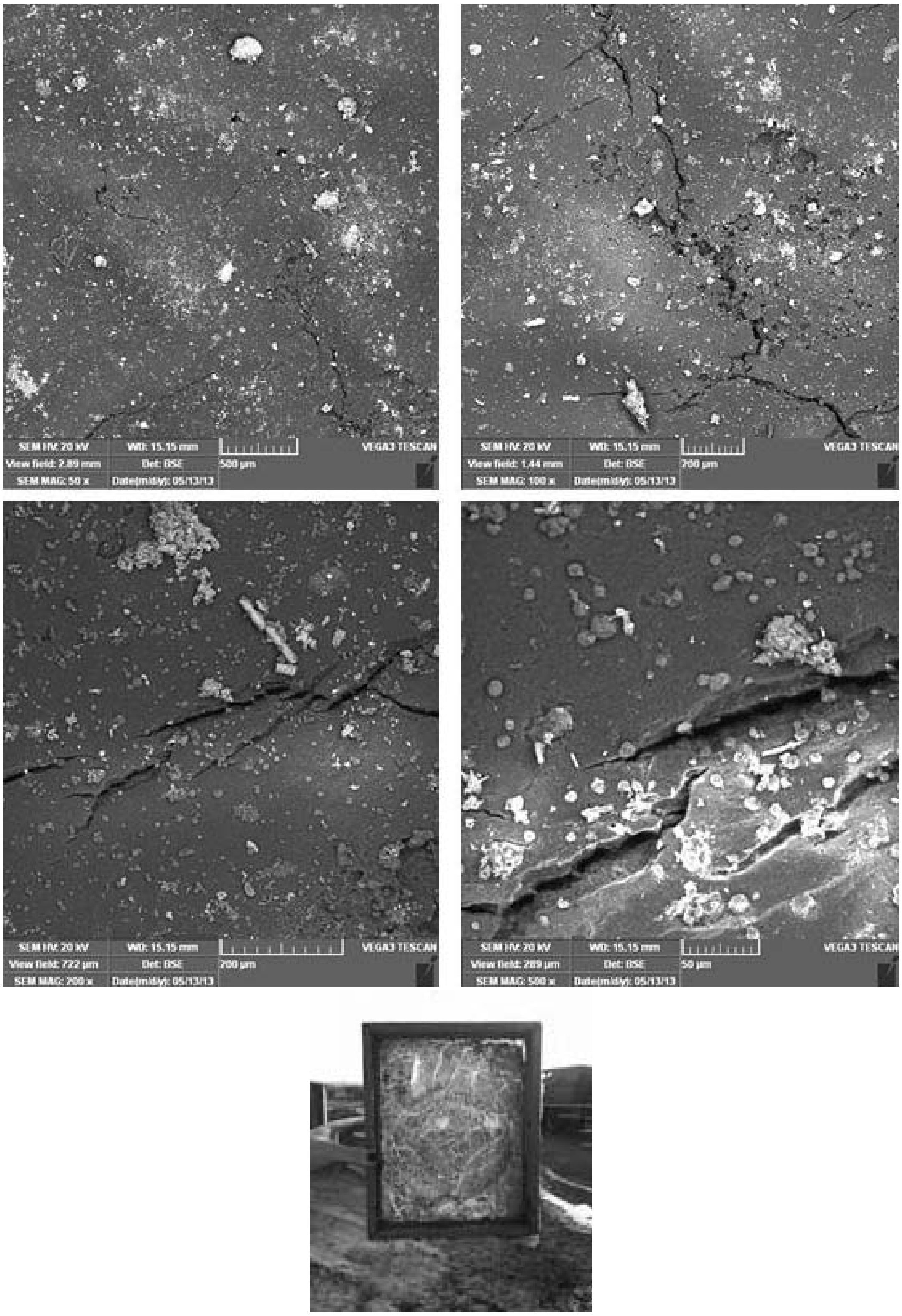

Fig. 5. Sample 4 (50×, 100×, 200×, 500×, real).

process, the material was still firm, and the only change was observed with regard to the colour of the printing (the colour changed from red to yellow).

Fig. 5 shows images of sample 4 and a photo of the sample after the termination of the composting process. The surface structure of the material has lost its smoothness, cracks are apparent. The sample showed a significant change in the structure. SEM images confirmed the ongoing process of biodegradation. After the expiry of the composting process in real conditions, sample 4 showed visual modifications, the sample broke into pieces. It was crumbling when touched.

Fig. 6 illustrates images of sample 5 and a photo of the sample after the termination of the composting process. Surface material disintegrated into very small fragments and a large amount of the film disappeared. As is evident from the SEM image, the ongoing biodegradation shows a substantial amount of holes and cracks of different sizes. The SEM observation showed that the film surface was totally eroded and its smoothness disappeared. During the composting process the monitored sample degraded by 90%.

Fig. 7 shows images of sample 6 and a photo of the sample after the termination of the composting process. After the composting process, the surface of the sample became dull and porous, with cavities. Surface material disintegrated into very small fragments and the large amount of film disappeared. The erosion of the polymer surface is clear. SEM images confirmed the biodegradation process.

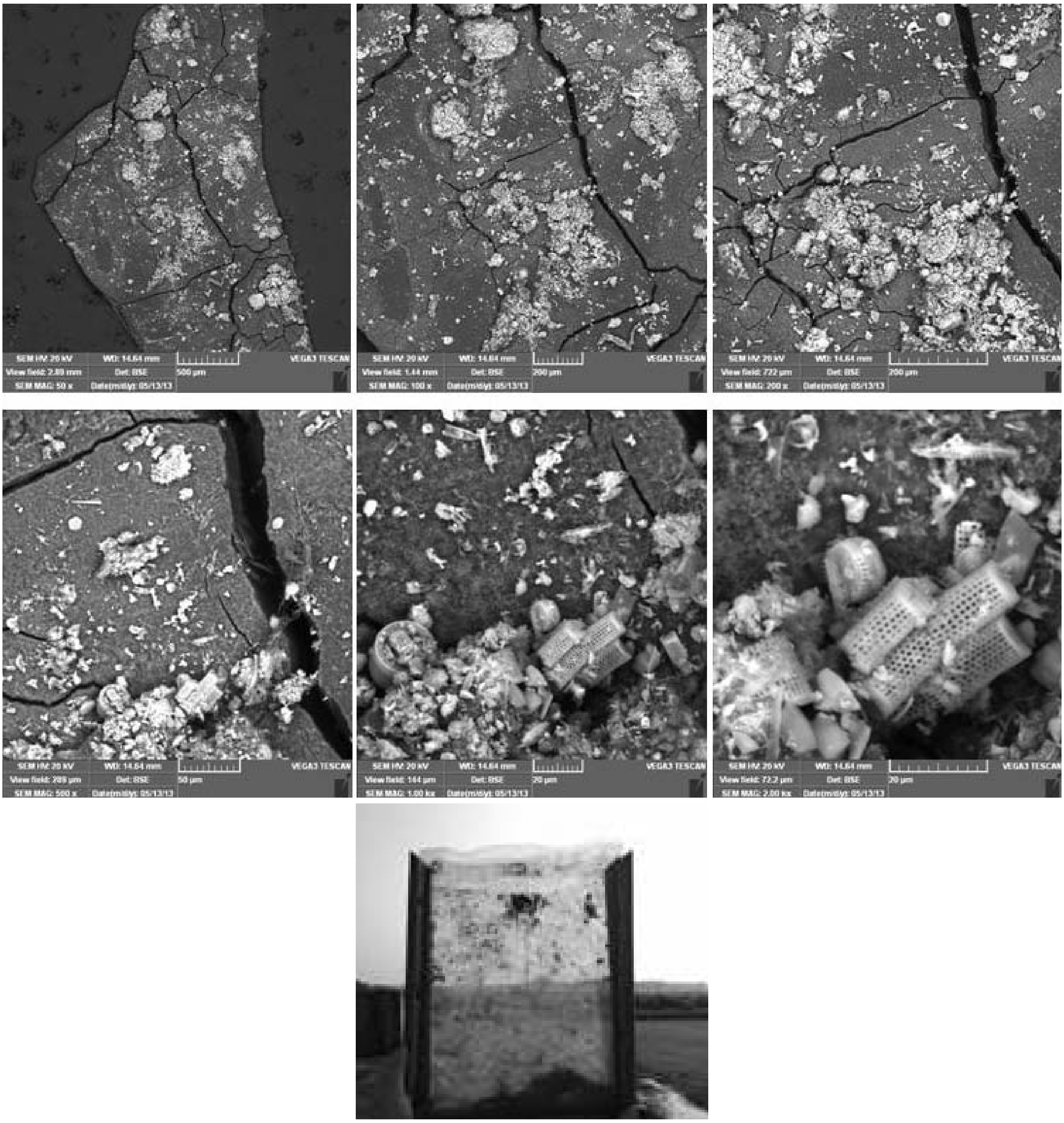

Fig. 6. Sample 5 (50×, 100×, 200×, 500×,1000×, 2000×, real).

During the composting process the monitored sample degraded by 90%.

Fig. 8 shows images of sample 7 and a photo of the sample at the end of the composting process. After the composting process the material disintegrated into small pieces, large parts of the film disappeared. As the image shows, the surface structure of the remaining material shows visible changes (deterioration of the surface – significant cracks and porosity). The SEM images confirmed the erosion of the polymer surface. Sample 7 degraded by 90% after the termination of the composting process.

All results of the study after the composting process are shown in Table 2. Symbol "+" means that the sample was decomposed. The degradation/biodegradation activity is

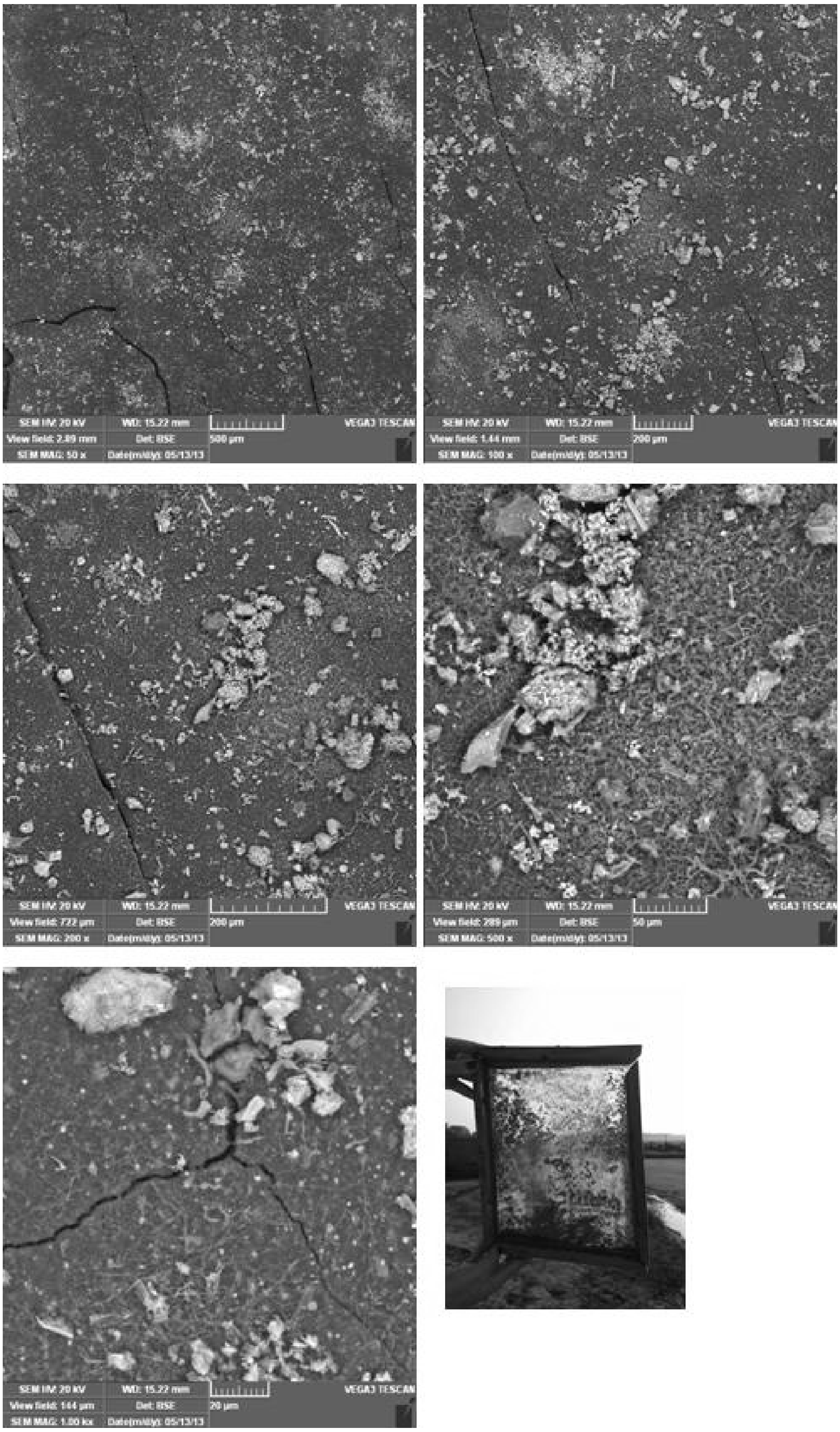

Fig. 7. Sample 6 (50×, 100×, 200×, 500× a 1000×, real).

designated as follows: + (week), ++ (mediums), +++ (strong). A negative result of degradation is indicated as "-."

Conclusion

With the increasing production and consumption of biodegradable/degradable plastics on the market, there is a need to determine the best disposal option of biodegradable/degradable plastic waste. The biodegradability and biodegradation rates of seven different samples were investigated under aerobic conditions. The experimental samples were placed in the compost pile and were checked and visually assessed during the experiment, which lasted 15 weeks (standards for the laboratory test required 12 weeks). All existing norms related to this issue describe tests in labora-

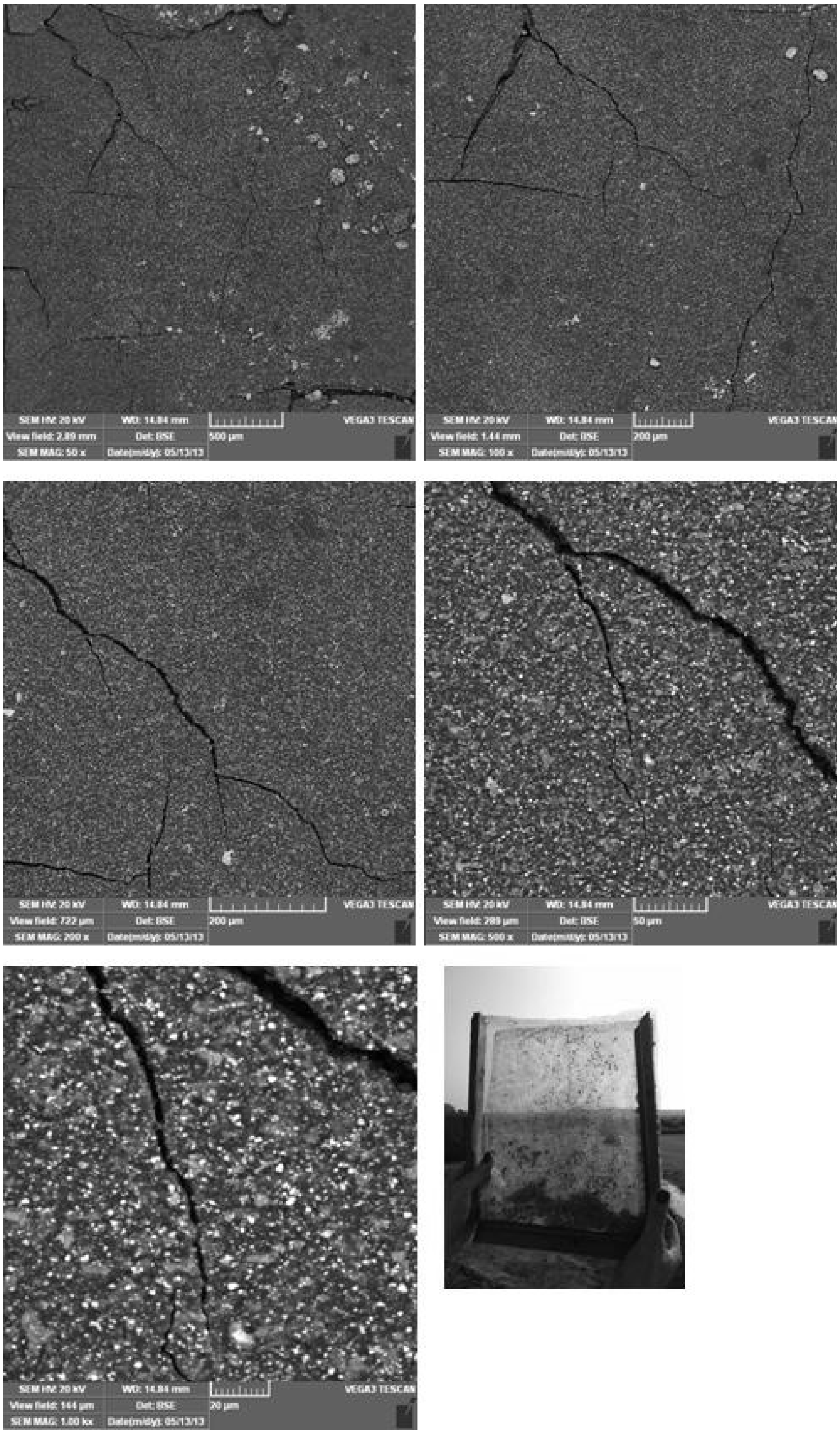

Fig. 8. Sample 7 (50×, 100×, 200×, 500× a 1000×, real).

tory conditions. Research in real conditions is not supported by norms, and methodologies describing procedures for the research of the decomposition of these materials in real conditions do not exists.

The goal of the experiment was to test the decomposition of the above-described samples in real conditions of the industrial composting plant. After the expiration of the experimental period it was found out that the samples with the additive (samples 1, 2, and 3) had not been decomposed, their color had not changed, and neither degradation nor physical changes had occurred. SEM photomicrograph images of the surface of the three samples confirm this statement. Samples 4, 5, 6, and 7 (certified as compostable) were decomposed. Samples 5, 6, 7 exhibited the highest decomposition rate (before the expiration of the set-up 15 weeks). For those samples holes of various shapes and sizes appeared first, then the films broke into pieces, and finally a large area of the films disappeared. The SEM observation (of the remaining pieces of the films) showed that the film surface of the samples was totally eroded and its smoothness disappeared. Sample 8 was a control reference sample to confirm that the conditions of decomposition were suitable during the experiment, which was the case.

The present study suggests that the biodegradable characteristics differed significantly, depending on the type of biodegradable/degradable plastics.

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