Indian Journal of Biotechnology
Vol 7, April 2008, pp 235-239

Impact of soil composting using municipal solid waste on biodegradation of plastics

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Received 5 February 2007; revised 20 August 2007; accepted 2 November 2007

Plastic wastes accumulating in the environment are posing an ever increasing ecological threat. In this context, an attempt was made to study the biodegradation of polyethylene films in the natural environment. The method suggested by ASTM standards, i.e. composting of polythene films with municipal solid waste, was adopted to examine the biodegradation of plastics in the natural environment. The samples were collected and tested for weight loss and reduction in tensile strength at 2 months interval for 12 months of composting. Loss of weight and reduction in tensile strength of polythene films were taken as the criteria indicating biodegradation of these materials. Composting of polythene films for 4 months did not show any degradation. After 4 months of composting, the loss in weight was 2.9-4.5% for HDPE films and 10.5-11.6% for LDPE films. Similarly, the reduction in tensile strength ranges from 16-20% for HDPE and 12-13% for LDPE films. The study indicates that the biodegradation of polythene films occur in natural environment at a very slower rate.

Keywords: Biodegradation, plastics, solid waste, soil composting, tensile strength

Introduction

The drastic rise in the use of non-biodegradable plastic materials during the past three decades has not been accompanied by corresponding development procedures for the safe disposal or degradation of these polymers. Polyolefin derived plastics, such as polyethylene, is currently used in the manufacture of plastic films for carry bags, cups, packaging films, garbage bags, etc. These plastics are characteristically inert and resistant to microbial attack and, therefore, they remain in the nature without any deterioration for a very long time. When the plastic solid waste is present in soil for long periods, it reduces water penetration into the soil, reduces soil fertility and prevents the growth of plant life and, thus, poses environmental problems.

A very general estimate of world wide plastic waste generation is about 57 million tons[1]. Hence, there is great demand for degradable or biodegradable plastics as a means of reducing the environmental impact related to the waste management of plastics. In this context, different degradable plastics have been developed, where inertness and resistance to microbial attack of plastics is reduced by incorporating starch and, later, pro-oxidants[2-4]. These synthetic biodegradable polymers are made in industries by mixing a non-biodegradable polymer with organic biodegradable starch or cellulose. In such cases, bacteria will digest the biodegradable part, and the non- biodegradable part will be broken down into small particles or powder. These kinds of "biodegradable" polymers are really an industry trick to gain the mark of biodegradability for the purpose of selling to consumers[5-6], where only the degradable part is eaten by the bacteria. The by-product of degradation is, thus, the by-product of bacterial digestion plus the original non-biodegradable polymeric component that is now in powder form. However, in case of true biodegradability, microorganisms utilize polyethylene films as a sole carbon source resulting in partial degradation. These bacteria colonize the polyethylene surfaces forming a biofilm. Cell surface hydrophobicity of these bacteria was found to be an important factor in the formation of biofilm on the polyethylene surface and which consequently enhanced biodegradation of the polymer[7].

The degradation of polythene can occur by different mechanisms, such as chemical, thermal, photo and biodegradation. Some studies have assessed the biodegradability of plastic films by measuring

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changes in physical properties or by observation of microbial growth after exposure to biological or enzymatic treatments. However, in most of the studies, degradation has been quantified by CO_2 evolution[5-8]. Biodegradation is, therefore, considered as a subset of the possible degradation routes, where degradation is defined as any physical or chemical change in a material caused by any environmental factor including light, heat, moisture, wind, chemical conditions or biological activity. Progressive biodegradation of film fragments is predicted once the film is plugged in to the top soil. The microorganisms present in the soil use the plastic material as carbon source for their growth and thereby degrade the plastic material[5]. It is claimed that a similar approach can be used to destroy the plastic litter[9]. Field tests burying plastic samples in soil have been widely conducted for their biodegradation because of the similarity to actual conditions of use and disposal. The biodegradation of plastics proceeds actively under different soil conditions according to their properties, because the microorganisms responsible for the degradation differ from each other and they have their own optimal growth conditions in the soil. The literature on biodegradation of synthetic polymers is sharply divided between those suggesting that microbial degradation can only occur if polymers could be degraded to extremely short chain lengths and those suggesting that synthetic polymers can also be metabolized at relatively high molecular weights[6]. Fungal and bacterial degradation of polymers may proceed by one or more mechanisms. The extent of degradation is likely to vary depending on the polymers' environment and desired application. Biodegradation of plastics is best estimated in the natural environment to which the wasted plastics are exposed.

Widespread studies on biodegradation of plastics have been carried out to overcome the environmental problems associated with synthetic plastic waste. Recent work has included studies on the distribution of synthetic polymer degrading microorganisms in the environment, the isolation of new microorganisms for biodegradation, the discovery of new degrading enzymes, and the cloning of genes for synthetic polymer-degrading enzymes[10]. In the present study, an attempt was made to examine the biodegradation of plastics in the natural environment, i.e. by composting with municipal solid waste and to identify the microorganisms responsible for such degradation.

Materials and Methods

Sampling

The study was carried out in two stages. In the first stage, polythene carry bags and cups, naturally buried in the compost, were recovered from the municipal compost yard of Kavali town for the examination of microorganisms associated with these materials. Care was taken to collect the samples from at least 6-month-old compost yard, so as to enable us to draw proper conclusions. In the second stage, the selected plastic carry bags were buried in the compost soil along with the municipal solid waste in order to facilitate biodegradation of plastics. Plastic carry bags of varying thickness, considered to be non-biodegradable, were also used in the study.

Composting of Samples

Degradation of plastics by microorganisms was measured according to the methods suggested by ASTM (American Society for Testing and Materials) D882 and D5988-96 standards[11,12]. Loss in weight and reduction in the tensile strength of plastic films after composting with municipal solid waste for specific period of time were taken as criteria of biodegradation of plastic films. Selected polythene bags were cut into 5 × 20 cm strips and used for the study. The weight (High Precision Electronic Analytical Balance, Model-AE-200, Metler, Mumbai) and tensile strength (Tensile Strength Testing Machine, Model-Statimat-4, Textechno Herbert Stein Gmbh & Co. KG, Monchengladbach, Germany) of these strips were taken before burying into the soil and after 2, 4, 6, 8, 10 and 12 months of burial in the soil.

Strips of polythene bags were buried at a depth of 5 cm in the compost soil collected from the municipal solid waste compost yard. The materials were allowed to degrade naturally under controlled soil conditions. Humidity of the soil is maintained at 40-50% by periodical sprinkling of water through out the period of study. The samples were collected at the intervals of 2, 4, 6, 8, 10 and 12 months of composting using sterile forceps. One set of samples are thoroughly washed using distilled water, shade dried and weighed for determining the final weight. The degradation is determined in terms of weight loss and reduction in tensile strength of the material over a period. Another set of samples are washed gently using sterile distilled water to remove soil debris. About 1 g of the material infested with bacteria and fungi was transferred into a conical flask containing 99 mL of sterile water. This content was shaken vigorously and serially diluted. To isolate microorganisms associated with the material, the pour plate method was adopted using the Zobell's agar medium for bacteria and the Martin Rose Bengal medium for fungi. For each dilution, three replicates were made. The plates were then incubated at 30°C for 2-7 d so as to determine bacterial and fungal counts of the samples. The same procedure was followed to estimate microbial counts associated with the plastic materials collected from the municipal compost yard.

Identification of Microorganisms

Among the bacterial and fungal colonies observed in the selected plates, the dominant colonies were isolated and sub-cultured repeatedly for getting pure colonies and then preserved in slants for further identification. The bacterial strains were identified according to the procedure suggested by Oliver[13]. The tests conducted were motility, glucose oxidation, penicillin sensitivity, and glucose fermentation for Gram-negative bacteria; and shape, dextrose fermentation, catalase and glucose fermentation for Gram-positive bacteria. The fungal strains are identified after staining them with cotton blue according to method suggested by Raper and Fennell[14].

Results and Discussion

Microorganisms Associated with Plastics

The microorganisms associated with the plastic films and cups recovered from the municipal solid waste compost yard were quantified and identified. The microorganisms identified from the samples collected from the solid waste compost yard revealed the presence of both bacteria and fungi in large number. The number of heterotrophic bacteria ranged from 25.40×10^3 to 62.75×10^4 in case of polythene films and 22.62×10^3 to 58.54×10^4 in case of plastic cups. While the fungal counts ranged from 18.32×10^2 to 34.36×10^2 in case of polythene films and 24.22×10^2 to 42.23×10^2 from plastic cups (Table 1). The average number of bacteria found in association with polythene films and plastic cups were 37.08×10^4 and 38.04×10^4, respectively. Similarly, the average fungal counts were 26.94×10^2 for the polythene films and 35.13×10^2 for plastic cups. The total number of microorganisms associated with the polythene films and plastic cups did not show much variation.

Table 1—Microbial counts of the degrading polythene films and plastic cups collected from municipal solid waste compost yard

Sample no.	Polythene films		Plastic cups	
	Bacterial count	Fungal count	Bacterial count	Fungal count
1	25.40×10^3	18.32×10^2	22.62×10^3	24.22×10^2
2	32.16×10^4	24.55×10^2	33.42×10^4	30.51×10^2
3	39.44×10^4	27.16×10^2	44.67×10^4	37.48×10^2
4	48.52×10^4	30.34×10^2	51.33×10^4	41.24×10^2
5	62.75×10^4	34.36×10^2	58.54×10^4	42.23×10^2
Mean	37.08×10^4	26.94×10^2	38.04×10^4	35.13×10^2
Standard error	10.03×10^4	2.71×10^2	9.85×10^4	3.42×10^2

The predominant microbial species identified from the sample polythene bags tested were *Bacillus* sp., *Staphylococcus* sp., *Streptococuus* sp., *Diplococcus* sp., *Micrococcus* sp., *Pseudomonas* sp. and *Moraxella* sp. Among the fungal species identified, *Aspergillus niger, A. ornatus, A. nidulans, A. cremeus, A. flavus, A. candidus* and *A. glaucus* were the predominant species. Similar types of organisms were reported earlier which associated with the plastic films buried in the soil[7,15]. Further, these soil microorganisms were reported to have the ability for degrading plastics[15]. These microorganisms utilize polythene films as a sole source of carbon resulting in partial degradation of plastics. They colonize on the surface of the polyethylene films or plastic cups forming a biofilm. Cell surface hydrophobicity of these organisms was found to be an important factor in the formation of biofilm on the polythene surface, which consequently enhanced biodegradation of the polymers[7]. However, further studies are required to determine which of the isolated microorganisms are efficient in degrading the plastics and polymers.

Biodegradation of Plastics

Weight Loss of Plastic Material

The weight loss of plastic films during composting in soil mixed with municipal solid waste could be taken as an indicator of biodegradation of plastics. Weight loss of plastic films and plastic cups were noticed after 4 months of composting and this loss was more apparent in the samples composted for 12 months (Fig. 1). Weight loss in plastic polythene bags, both 10 micron thick high density polyethelene (HDPE) and 20 micron thick low density polyethelene (LDPE), were not observed in the samples composted for less than 4 months. This lag period of 4 months could be attributed to the delay in the formation of biofilm by the soil microorganisms[7]. However, a lag

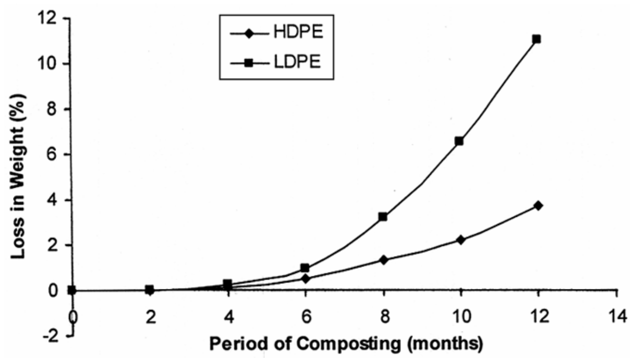

Fig. 1—Weight loss of polythene films during composting.

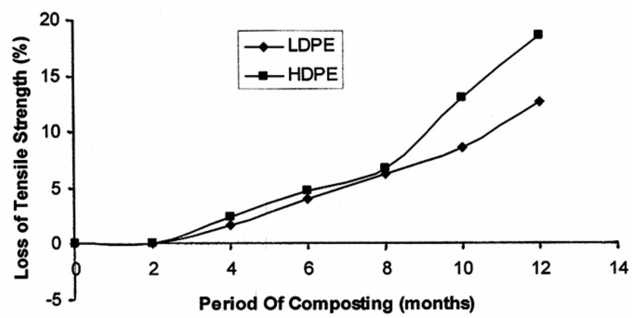

Fig. 2—Loss in tensile strength of polythene films during composting.

phase of 4 wk was observed by Orhan *et al*[7] for both HDPE and LDPE, after which a slight weight loss was recorded. They noticed a degradation of 1.3 and 2.1% in the cases of HDPE and LDPE, respectively after 9 months. In the present study, the weight loss in plastic films was only 3.68% in the case of HDPE even after 12 months of incubation, while it was 11.01% in the case of LDPE. However, the effect of period of composting and type of plastic (HDPE & LDPE) on weight loss of plastic were statistically insignificant in a 2-way Anova. The calculated F-value was 3.9506 and critical F-value was 4.2838 in the case of months of composting and the calculated F-value was 3.5344 and critical F-value was 5.9873 in the case of type of plastics.

Table 2—Correlation between weight loss and tensile strength of polythene films during composting

Time of composting (months)	HDPE1	HDPE2	LDPE1	LDPE2
	Percent weight loss			
0	0	0	0	0
2	0	0	0	0
4	0.14	0.13	0.10	0.42
6	0.41	0.53	0.93	0.89
8	1.23	1.45	3.12	3.23
10	2.05	2.37	6.86	6.12
12	2.87	4.48	11.54	10.47
Mean	0.9571	1.28	3.2214	3.0185
Standard error	0.4289	0.6290	1.6775	1.5015
	Percent loss in tensile strength			
0	0	0	0	0
2	0	0	0	0
4	2.17	2.56	2.29	1.10
6	4.35	5.12	4.58	3.29
8	5.80	7.70	6.87	5.49
10	13.04	12.82	8.40	8.79
12	20.28	16.67	13.00	12.10
Mean	6.52	6.41	5.02	4.3957
Standard error	2.8494	2.4235	1.8032	1.7633
Correlation coefficient	0.9832	0.9658	0.9473	0.9776

Reduction in Tensile Strength

Films or fibers in contact with soil over long periods were expected to depict loss in tensile strength. Loss in tensile strength is the most relevant practical criterion in determining degradation of films and fibers. Tensile strength of plastic films buried in soil mixed with municipal solid waste is shown in Fig. 2. Loss in the tensile strength was low in the first 4 months of composting for all the samples tested and it increased with increase in composting time. The loss in tensile strength was 18.48% for HDPE, and 12.55% for LDPE. Thus, it could be noted that both HDPE and LDPE remained relatively resistant even after composting for 4 months and became sensitive to microbial attack after that. The hydrophobicity of polyethylene is the main reason for its resistance to degradation by the microbial enzymatic systems. If these films are starch based polyethylene films, starch in these films allows water adsorption and provide suitable conditions for microbial colonization and degradation of starch and esters resulting in the disintegration of these films. The degradation of mechanical properties might result from attack by microorganisms or by change in the soil chemistry controlled by microbiological activity.

Analysis of variance of months of composting and types of plastic (HDPE or LDPE) indicated that period of composting has significant effect on tensile strength of plastics, whereas type of plastics has no significant bearing on tensile strength. Therefore, the study indicates that composting of plastic films in the soil causes biodegradation of plastics irrespective of their type. The calculated F-value was 24.0545 and critical F-value was 4.2838 in the case of period of composting, and the calculated F-value was 3.8463 and critical F-value was 5.9873 in the case of type of plastics used in the study.

Correlation between Weight loss and Tensile Strength

As two measures of biodegradation were used in the study, correlation between these two measures i.e,. percent weight loss and percent loss in tensile strength of plastic films was estimated (Table 2). The estimated correlation coefficient ranged from 0.9658 to 0.9832 for HDPE films and 0.9473 to 0.9776 for LDPE films, indicating a strong positive correlation between weight loss and tensile strength of polythene films. If one factor is affected by microbial attack, the other factor is also affected at the same time. When the soil microorganisms utilize plastic material as a source of energy for their growth, the weight of the plastics will be reduced. Consequently, the tensile strength of plastic films is also reduced due to loss in weight of these films.

Summary

Plastic wastes accumulating in the environment are posing an ever increasing ecological threat. The most problematic plastic in this regard is probably polyethylene, which is one of the most inert synthetic polymers and being resistant to microbial attack. It is evident from the study that degradation of polythene films, both HDPE and LDPE, in the natural environment is slow and, therefore, posses a serious environmental concern. A new generation of environmental friendly polyethylene containing a minimum of 9% starch and pro-oxidant additives are highly recommended for use since their degradation in natural environment is much faster.

Acknowledgement

The authors are thankful to Sri K Hari Babu, Laboratory In-charge of Textiles Committee Laboratory, Hyderabad for his help in testing the sample for weight loss and tensile strength.

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