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Mechanical and chemical analysis of degraded plastic bags exposed in air, water, and soil

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ABSTRACT

This study is aimed at analyzing the mechanical behavior of low-density polyethylene (LDPE) plastic bags exposed for three years to air, immersed in polluted and tap water, buried in soil, and exposed on the soil surface. The pH and conductivity analyses for polluted water resources, clean water and soil extract were performed. Semi-quantitative chemical analysis of soil using X-ray fluorescence spectrometry (XRF) was performed. For the mechanical assay, a 100 kN load cell was used subjected to a traction with obtaining strain curve x deformation. The aqueous soil extract is rich mainly in nitrate, sulfate, and calcium. The polluted water in which the bags were immersed had a high concentration of chlorides, and contained nitrate, sodium, and calcium. Finally, tap water contained mostly sulfate, sodium, calcium, and chloride ions. However, the chloride content of polluted water is ten times the content of tap water. The tensile strength and elongation of degraded samples are lower than the reference, confirming the process of degradation. An exception was the deformation of plastic bag buried in soil which was the highest.

Keywords: Plastic bags; Environmental degradation; Tensile strength.

1. INTRODUCTION

Plastic bags have been manufactured on a large scale since 1970 and has become a serious concern, contributing to the increase of solid urban waste, and contaminating the environment [1–4]. Literature describes different approaches for assessing their degradation in varied conditions, even in gastrointestinal fluids of sea turtles [5] and marine environments [6].

OJEDA *et al*. [7] evaluated the degradation of polyethylene (PEs) plastic bags by using high density polyethylene (HDPE), and linear low-density polyethylene (LLDPE) formulated with pro-oxidant additives as test material. After a year of exposure, waste samples of the plastic bags were incubated in substrates (compounds of solid urban waste, perlite, and soil) at 58°C and 50% humidity. The authors observed the PE degradation during natural weathering. The growth of fungi of the genus Aspergillus and Penicillium was observed in PE films containing pro-oxidant additives exposed to weathering for a year or more. PE conventional films exposed to natural weathering showed little biodegradation. GAJENDIRAN *et al*. [8] studied the efficient degradation of LDPE by the isolate Aspergillus clavatus (a fungus) for duration of 90 days exposure. The degradation methods studied in this work can be conducive to the development of fungi, such as pond water or moist soil, which can accelerate the degradation of plastic bags.

Polyethylene is very resistant to biodegradation due to its high hydrophobicity and its long carbon chains [9, 10]. However, the study of degradability of plastic materials under controlled and natural composting environments for three years or more is scarce in literature. PORTILLO *et al*. [11] reported that although the oxo-degradable additive increased the abiotic (temperature and ultraviolet radiation) photodegradation of PE, the molecular weight reduction in compost was not enough to reach the maximum biotic degradation level established by international standards for biodegradable materials. LUZ *et al*. [12] evaluated the abiotic and biotic degradation of oxo-biodegradable plastic bags by Pleurotus ostreatus and observed that mechanical modifications and reduction of titanium oxide pigment were necessary to initiate plastic degradation. NADDEO *et al*. [13] observed that the change in the carbonyl index and the mechanical parameters with the exposure time

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allowed the determination of the point beyond which the LLDPE becomes useless during weathering. A recent study [14] explored the potential of a constructed tri-culture yeast consortium, designated as DYC, isolated from termites for the degradation of low-density polyethylene (LDPE). TIWARI *et al*. [15] reported the efficiency of landfill microbial communities in biodegradation of polyethylene and nylon 6,6 microplastics. To our knowledge, literature does not report a study of mechanical properties of degraded plastic bags exposed for three years to environment, as reported in this study.

2. MATERIALS AND METHODS

The bags were commercial carrier bags supplied by the manufacturer, in 2011. For each of the five environment conditions, two samples of different sizes were prepared: 40 mm × 65 mm with a mass of 0.0403 g, and 65 mm × 90 mm with a mass of 0.1002 g, with thickness of 21 μm and density of 0.12 g/mm^3.

The aqueous extract of the soil was prepared according to the following procedure: a sample of 500 g of wet soil was dried at room temperature for 48 hours, and the residual moisture was measured. A sample of 10 g of soil was weighed and dried in an oven for one hour at 105º C. After cooling in air, the sample was weighed, and the procedure was repeated until constant mass. The moisture content was obtained by measuring the difference between the initial and final mass. The sample was ground and submitted to screening with sieves of 2.5 mm. Pieces of leaves, roots and branches were removed. A solution of 200 g of dry soil and 1000 mL of water was prepared in a beaker and agitated after each interval of 30 minutes for 8 hours by using a glass stick. The beaker was coated with a polymeric film, and the mixture remained at rest for 48 hours. After decantation of the soil, the liquid phase (aqueous soil extract) was obtained. The methodology was adapted from literature [16].

The pH and conductivity analyses for polluted water resources, clean water and soil extract were performed in triplicate. The pH analyses were performed using a digital pH meter bench, Digimed DM-22, and conductivity was measured using a conductivity Ion DDS-12DW.

Bags of low-density polyethylene (LDPE) provided by the manufacturer were immersed in polluted (PW) and tap water (TW), exposed in air (identified as AIR), exposed on the soil surface (SS) and buried in soil (BS), and tests were performed in duplicate. The reference sample was named as REF. Bag of low-density polyethylene (LDPE) were immersed in a volume of 155 mL in a bottle with water taken from the Pampulha Lagoon, in Belo Horizonte, Brazil. Bottles were protected with a cloth to preserve the characteristics of environment. The water was renewed frequently due to evaporation losses. To minimize error propagation, the sample was always collected at the same point of the lagoon (geographic coordinates: 19 50’55” 43 S 58’ 27”). The bags were immersed in a volume of 155 mL of tap water. As with polluted water, the bottles were masked with a cloth, and tap water was frequently renewed because of evaporation losses. This procedure was developed by authors.

The bags were placed into polyester mesh bags leaked, to allow air circulation. The bags were tied on a string, leaving the bags in touch with the outdoors in a shaded area. The intention was to simulate a plastic bag stuck in a treetop, with no exposure to the sun. This environment is in an urban area. The bags were left on a layer of soil in a container with a volume of 2 L. The soil was taken from the same place of Pampulha Lagoon where the water was collected (geographic coordinates: 19 50’55” 43 S 58’ 27”). The bags were in contact with air and exposed to the environment, also receiving rain. The bags were buried in a layer of soil collected from the same location of the soil used for exposure of plastic bag on the soil surface (geographic coordinates: 19 50’55” 43 S 58’ 27”). The containers used had a volume of 2 L. The degradation testing was performed for three years. This methodology was developed by authors.

Semi-quantitative chemical analysis of soil using X-ray fluorescence spectrometry (XRF) was performed using a PHILIPS PW 2400 Spectrometer and pressed tablets. For the mechanical assay, the Instron 5882 equipment was used with 100 kN load cell subjected to a traction with obtaining strain curve x deformation. Each test piece had a dimension of 50 mm × 20 mm. The travel speed was set to 500 mm/min according to ASTM D3039 standard [17].

3. RESULTS AND DISCUSSIONS

3.1. Characterization of soil and water

The environments were analyzed, and results are shown in Table 1. The aqueous soil extract is rich mainly in nitrate, sulfate, and calcium. The polluted water in which the bags were immersed had a high concentration of chlorides, and contained nitrate, sodium, and calcium. Finally, tap water contained mostly sulfate, sodium, calcium, and chloride ions. However, the chloride content of polluted water is ten times the content of tap water.

The X-ray fluorescence spectrometry analysis identified that the soil used had a high silicon, aluminum, and oxygen contents; moderate levels of iron; low amounts of magnesium and titanium; and traces of sodium, phosphorus, sulfur, zinc, copper, manganese, chromium, calcium, potassium, and zirconium.

Table 1: Chemical composition of media (mg/L).

MEDIUM	F^-	Cl^-	NO_2^-	Br^-	NO_3^-	SO_4^{2-}
Soil extract	0.282 ± 0.085	7.054 ± 0.366	0.206 ± 0.508	0.596 ± 0.441	24.588 ± 0.369	21.869 ± 0.361
Polluted water	0.498 ± 0.083	72.598 ± 0.809	–	0.618 ± 0.441	38.303 ± 0.462	5.644 ± 0.399
Tap water	0.577 ± 0.082	7.519 ± 0.363	–	0.587 ± 0.441	1.988 ± 0.426	18.364 ± 0.357
	Li^+	Na^+	NH_4^+	K^+	Mg^{2+}	Ca^{2+}
Soil extract	–	4.404 ± 0.336	–	1.034 ± 1.470	1.114 ± 0.526	18.76 ± 0.837
Polluted water	0.007 ± 0.209	21.024 ± 0.337	1.968 ± 0.485	5.410 ± 1.414	3.154 ± 0.507	25.882 ± 0.806
Tap water	–	4.624 ± 0.335	–	0.79 ± 1.481	1.204 ± 0.525	3.64 ± 0.941

Table 2: Conductivity and pH of environments.

	CONDUCTIVITY (µs/cm)	TEMPERATURE (°C)	pH
Polluted water	560.7 ± 3.2	24.9 ± 0.1	8.47 ± 0.04
Soil extract	236.0 ± 1.7	25.0 ± 0.1	8.32 ± 0.08
Tap water	137.3 ± 1.0	25.3 ± 0.1	8.63 ± 0.01

Polluted water is the environment with the highest conductivity [18] as shown in Table 2, and tap water showed the lowest conductivity (Table 2). The pH of all media is 8, lightly alkaline (Table 2).

3.2. Visual observation of degraded plastic bags

The plastic bags after three years of exposure in five environmental conditions are shown in Figure 1. The samples of the bags showed few visual modifications after a set period of degradation.

3.3. Mechanical test analysis for traction

Results of mechanical behavior of plastic bags exposed on five environments are shown in Table 3 and Figure 2. The tensile strength of degraded samples is lower than the reference, confirming the process of degradation. VARGHA *et al*. [19] reported that tensile strength of commercial MDPE film (PE340) showed a monotonous increase up to six months of exposure in soil, which might be due to initial cross-linking. However, after one year, the tensile strength decreased and reached the initial value. In this work, after three years of exposure in soil, the tensile strength of PE films decreased well below the value of the reference sample. O'BRINE and THOMPSON [6] exposed oxo-biodegradable plastic bags, compostable and standard polyethylene in marine environment and observed that the tensile strength of all materials decreased during exposure, but at different rates. During the investigated eight (8) months of atmospheric and sea weathering of high-density polyethylene, 10 % and 6 % decrease in ultimate tensile strength was reported for the two different environments, respectively [20]. VARGHA *et al*. [19] observed that all samples studied of middle density polyethylene films suffered physical degradation in soil.

The elongation at break is another relevant parameter to observe the behavior of the polymer. After one year of exposure of middle density polyethylene in soil, VARGHA *et al*. [19] did not observe change in elongation at break of polymer. In this work, elongation at break of plastic bag buried in soil was the highest. MOTAHARI and ABOLMAALI [21] reported deformation characteristics of the buried high-density polyethylene pipelines. The results show that many buried HDPE pipelines have deformations more than the commonly acceptable limits along multiple locations within each pipeline. One hypothesis for the high elongation of the plastic bag buried in the soil is that the soil may contain plasticizers such as hydrocarbons. And the breakage of fibrils and chain scission occurred, and small molecules can act as plasticizer.

It is interesting to note that the species present in polluted water did not affect the mechanical properties of the bags, which were mainly influenced by the type of medium in which they were exposed: water, air or soil (Figure 2d and e). The bags degraded in water showed a gradual reduction of force per area after the maximum of tensile strength. The samples buried in the soil or degraded in the soil surface reach the maximum of tensile strength to the tension remains high until a sharp decrease in tension occurs, probably due to a sudden reduction in area. The medium determines the shape of the stress × strain curve.

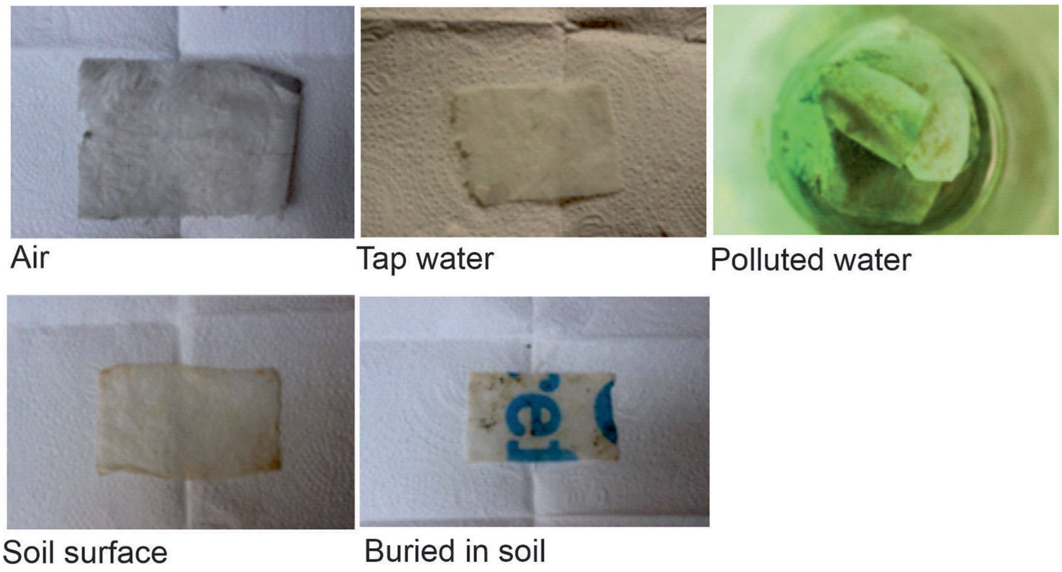

Figure 1: Plastic bags after three years of exposure in five conditions.

Table 3: Tensile test results for LDPE in different environments.

PARAMETER	UNIT	REF	BURIED IN SOIL	POLLUTED WATER	SOIL SURFACE	TAP WATER
Maximum Extension	mm	62.05	127.76	5.31	5.14	7.46
Maximum Load	N	11.57	3.97	7.13	7.01	5.11
Deformation	mm/mm	2.39	4.91	0.20	0.20	0.29
Tensile Strength	MPa	51.41	17.67	31.67	18.58	22.72

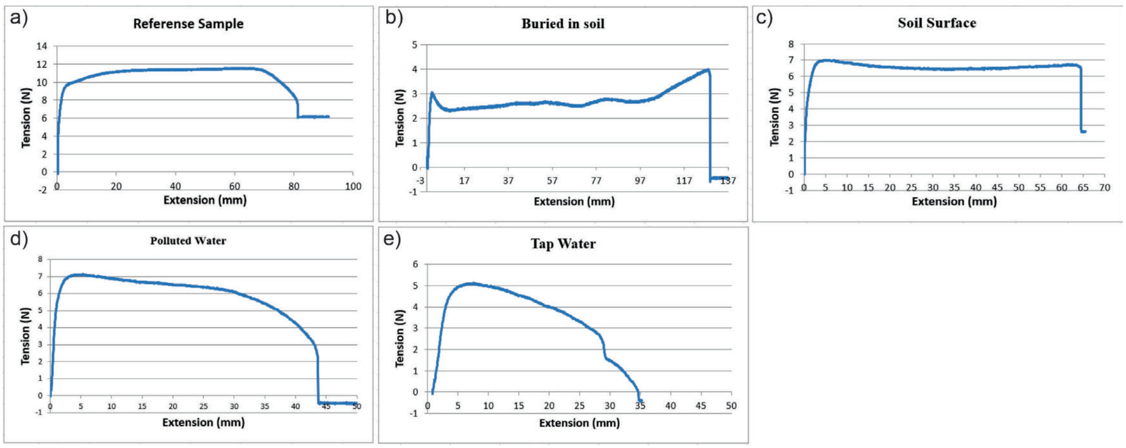

Figure 2: Tensile test for plastic bags: a) reference sample, b) buried in soil, c) exposed on soil surface, d) immersed in tap water, e) immersed in polluted water.

4. CONCLUSIONS

Low density polyethylene (LDPE) plastic bags were exposed for three years to air, immersed in polluted and tap water, buried in soil and exposed on the soil surface, simulating environmental conditions in which the plastic waste is released without a correct disposal.

The tensile strength and elongation of degraded samples are lower than the reference, confirming the process of degradation. An exception was the deformation of plastic bag buried in soil which was the highest since the soil may contain plasticizers such as hydrocarbons.

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