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DEGRADATION OF DEGRADABLE PLASTICS ON SEVERAL SOLID AND LIQUID MEDIA

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Abstract: Plastics on the market are usually made by synthetic polymers that are difficult to decompose in nature. To reduce the impact of plastic waste, nowadays biodegradable and degradable plastics have been introduced into the market. The availability of degradable plastics on the market attracts local government in Bandung to use degradable plastics for waste storage especially on the road side. Therefore, this study evaluates the end life of degradable plastics in solid and liquid media: soil, waste, composting and water. Two types of plastic materials, @Ecoplas and @Oxium are investigated. @Ecoplas is made from natural materials, such as starch, so it can be degraded biologically. @Oxium is made from additional addictive substance that is mixed into pure plastic raw materials in order to speed up the oxidation process. The plastics were inserted into the soil and waste media for 90 days, composting media for 50 days, anaerobic condition for 21 days, and the river media for 21 days. To confirm the degradability, a series of measures was conducted by measuring the weight and tensile strength. Scanning Electron Microscopy (SEM) test was also conducted to see the morphology of plastics during the experiments. The average of weight loss for @Ecoplas was up to 31% and for @Oxium was up to 20% during 90 days in waste media, whereas, in the soil the average weight loss for @Ecoplas and @Oxium was up to 33% and 28% during 21 days consecutively. For the tensile strength test, @Ecoplas has decreased 25-27% and @Oxium has decreased 16-17% in soil and waste media.

Keywords: biodegradable plastics, degradable plastics, degradability, solid media, liquid media

INTRODUCTION

In the past, plastic polymeric materials have been designed to resist degradation. However, with mounting environmental and legislative pressure to reduce plastic and packaging wastes, there has been an increased demand for biodegradable polymers that can decompose in the environment. In Bandung, there are two types of degradable plastics which are commercially available, biodegradable and degradable plastics, for example with the brands @Ecoplas and @Oxium. @Ecoplas is one of the new brand of biodegradable plastics. Biodegradable plastics are plastics that can be degraded with the help of microorganisms into environmentally friendly compounds, carbon dioxide(CO_2), water(H_2O) and biomass. @Oxium is one of the brand from additive that is mixed into pure plastic raw materials in order to speed up the oxidation process.

Are degradable plastics (DP) or biodegradable plastics (BP) can be the answer to solve the environmental pressure caused by conventional plastics? To find the answer, the need to know how DP or BP degrades in the environment is important. Then, a decision on to promote the BP or DP can be justified. Therefore, this study objective is to determine the level of degradation of plastic @Ecoplas and @Oxium. The study was conducted on six media degradation testing, the soil media, waste media, composting media, anaerobic condition, and river media. The media and condition were chosen based on the possibility of end life of plastics.

LITERATUR REVIEW

When biodegradable plastics started entering the market, there were a series of misconceptions about the term degradable and biodegradable. Many plastics entered the market with biodegradable labeling, but only disintegrated and did not completely biodegrade. These plastics have been commercially available since 1990 and can be produced either from plant origins, such as strach or by bacteria. Therefore, in order to avoid misconceptions, several standards in the area of degradable as well as biodegradable plastics have been developed by national standards bodies including USA (ASTM), the International Organization for Standardization (ISO) and others (Mohee et al., 2008).

As per the ASTM standard D5988-03, biodegradability of plastic materials has been defined as the capability of undergoing decomposition into carbon dioxide, methane, water, inorganic compounds or biomass predominantly by the enzymatic action of microorganisms. The standard requires 60-90% decomposition of the plastic within 60-180 days in composting environment. Degradable plastic is defined as a plastic designed to underdo a significant change in its chemical structure under specific environmental conditions, resulting in a loss of some properties that may vary as measured by standard test methods appropriate to the plastics and the application over period of time that determines its classification.

Figure 1 indicates how degradation differs from biodegradation.The degradable stage stops at the fragmentation of polymers. This occurs by the action of heat, moisture, sunlight and/or enzymes that shorten and weaken the polymerchains resulting infragmentation residues and cross-linking to create more intractable persistent residues. It is only if the fragmentsare consumed by microorganisms as food and an energy source that the plastic polymer is said to be biodegradable.

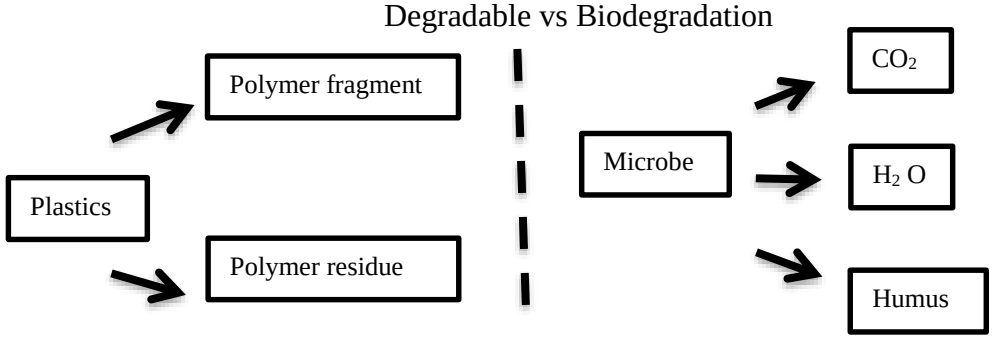


Figure 1 Degradation versus biodegradation process

MATERIAL AND METHODS

Types of plastics that were sampled in this research are @Ecoplas and @Oxium. @Ecoplas is a biodegradable plastic film samples which are made from a mixture polyethylene with starch. This plastic has a thick 20µm. @Oxium is degradable plastic which are made from a mixture polyethylene with additives added. This plastic has a thick 30µm.

Two types of controls are used namely positive and negative controls. A filter paper is used as positive control. A positive control is a specimen that can be degradaed completely. Negative control came from conventional plastics on the market, HDPE (High Density Polyethylene). A negative control is a specimen that can't degraded along this test.

a. Determination of biodegradability under soil media

Soil media which were applied in this study was a soil without compost or nutrient added. In this condition, the soil media were dropped into the reactor, size 1x1x1 m. The samples plastic of @Ecoplas, @Oxium and HDPE as a negative control were inserted into the reactor which already contains the soil. These samples were inserted on three different heights, 30 cm, 60 cm and 90 cm from the bottom. The study was carried out at the media for 90 days and sampling once every seven days. The soil parameters used for monitoring were moisture content, pH and temperature.

b. Determination of bioderadability under waste media

In this condition, the piles of waste were derived from TPS *Caringin* and the experiments were conducted at the Sarimukti landfill. The piles of waste were droped into the size 2x1x1m. The samples plastic of @Ecoplas, @Oxium and HDPE as a negative control were inserted into the piles of waste. These samples were inserted on three different heights, 30 cm, 60 cm and 90 cm from the bottom. The study was carried out at the media for 90 days and sampling once every seven days. The waste parameters used for monitoring were moisture content, volatile solids, pH and temperature

c. Determination of biodegradability under composting media

A reactor, 60x50x120 cm was used for aerobic composting. The composting materials consisted of 25.5 kg of kitchen waste, 30 kg of yard waste, 2.5 kg of paper and 8.2 kg of water. The carbon-to-nitrogen ratio of the mix was 27.9, where the carbon content was determined based on the ash percentage and the nitrogen content by the Kjeldahl method.

The moisture content was adjusted to 55% by the addition of water. The sample plastics of @Ecoplas, @Oxium, HDPE and filter paper, 0.5 g each, were cut into sizes 0.5 x 0.5 cm and were placed in 17.5 mm -18.0 mm bags. These bags were then inserted within the compost pile at different positions, 40 and 60 cm from the bottom.. The biodegradation of these test samples were determined through mass loss analysis. The composting parameters used for monitoring were moisture content, volatile solids content, pH and temperature.

d. Determination of biodegradability under anaerobic conditions

This part of the study was performed to investigate the biodegradability potential of degradable/biodegradable plastic under an anaerobic medium (sludge) as per ASTM D5526-94d test method to determine anaerobic biodegradation of plastic materials under accelerated landfill conditions (Figure 2). The samples plastic of @Ecoplas, @Oxium, HDPE and filter paper, I gram each were cut finely to film sizes of 0.5 x 0.5 mm as specified in ASTM D5526-94d. The inoculum was an anaerobic sludge obtained from the *Bojongsoang* waste water treatment plant where

effluents of domestic waste from Bandung city were treated. This investigation consisted of thoroughly mixing the plastic and cellulose filter paper samples by using stirrer with constant spin for 2 hours. The samples were analyzed in dulicate and one set was assessed without addition of any plastics.

Figure 2 Experimental set-up under anaerobic condition

e. Determination of biodegradability under river water sample

River water sample which were used in this study came from Cikapundung river. In this condition, Cikapundung River water sample was then dropped into the reactor, size 60x40x50 cm.The samples plastic of @Ecoplas, @Oxium and HDPE as a negative control were inserted into the reactor. The study was carried out at the media for 21 days and sampling once every seven days. The water parameters used for monitoring were Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Dissolved Oxygen (DO) and alkalinity.

RESULTS AND DISCUSSION

a. Degradability test under soil media

The percentage of plastic degradation can be calculated as follows:

$$\%\ Plastic\ Degradation : \frac{(weight\ of\ plastic\ at\ the\ beginning - weight\ of\ the\ plastic\ at\ the\ end)}{weight\ of\ plastic\ at\ the\ beginning} x100\%$$

Table 1 Percent Degradation of Plastics on Soil Media

Sample	Height (from the bottom)	Weight T_0(gram)	Weight T_{90}(gram)	% Degradation
HDPE	30 cm	0.1162	0.1123	3.350
	60 cm	0.1122	0.1121	0.080
	90 cm	0.1168	0.1167	0.085
@Ecoplas	30 cm	0.2911	0.1962	32.60
	60 cm	0.2875	0.1941	32.48
	90 cm	0.2825	0.1886	33.23
@Oxium	30 cm	0.3720	0.3021	18.79
	60 cm	0.3750	0.2830	24.53
	90 cm	0.3880	0.2780	28.35

It can be seen from Table 1, the percent degradation of HDPE only 0.08 to 3.35 %. It shows how HDPE very slowly decompose in nature compare to other plastics. The sample pastic of HDPE will not be degraded at its optimum time for only 90 days. According to the results of percentage degradation for @Ecoplas, it can be seen that the weight of plastic at height of 30 cm, 60 cm and 90 cm were not too different significantly. At height of 30 cm from the bottom, plastic degraded 32.6 %, at height of 60 cm from the bottom, plastic degraded 32.48 % and at height of 90 cm from the bottom, it degraded 33.23 %.

The results of percent degradation for @Oxium were different. It can be seen that the weight of @Oxium at height of 30 cm from the bottom had the smallest percent degradation, 18.79 % , whereas at a height of 60 cm from the bottom the sample plastic had a percent degradadation 24.53 % and the highest degradation occurs at a height of 90 cm from the bottom, 28.35 %. According to Mohee et al., (2008), @Oxium was an Oxo-degradable type, where the type of plastic will degrade well when there is the influence of specific environmental conditions, such as sunlight and moisture.

b. Degradability test under waste media

After being tested for 90 days, at the beginning the temperatur of the piles of waste was 34°C and at the end the temperature was 29°C. The moisture content in this experiments was about 50-60%. According to Damanhuri and Padmi (2010), the moisture content of municipal waste in Indonesia is about 60%. It happened because the waste composition was dominated by organic materials. In this experiments, pH value stands at 5.9-6.2. According to Tchobanoglous et al., (1993), a stable pH in the digester to degrade organic material is 7. If the pH value is far above the 7 there will be a loss of osmotic pressure on microorganism, while the pH value is too low will cause decomplectation of major ions from minerals and organic matter.

Table 2 Percent Degradation of Plastics on Waste Media

Sample	Height from the bottom	Weight T_0 (gram)	Weight T_{90} (gram)	% Degradation
@Ecoplas	30 cm	0.2890	0,2010	30,44
	60 cm	0.2921	02010	31.18
	90 cm	0.2955	0.2200	31.11
@Oxium	30 cm	0.3660	0.3210	12.29
	60 cm	0.3680	0.3020	17.93
	90 cm	0.3620	0.2880	20.44
HDPE	30 cm	0.1140	0.1130	0.870
	60 cm	0.1120	0.1090	2.670
	90 cm	0.1130	0.1120	0.880

It can be seen from Table 2, the percentage degradation of HDPE only 0.8 to 0.88 %. For @Ecoplas, it can be seen that the weight of plastic at height of 30 cm, 60 cm and 90 cm were not too different significantly. At a height of 30 cm from bottom, plastic degraded 30.44 %, at height of 60 cm from the bottom, plastic degraded 31.18 % and at height of 90 cm from bottom, it degraded 31.11%. The result of percent degradation for @Oxium was significantly different. It can be seen that the weight of @Oxium at height of 30 cm from the bottom had the smallest percent degradation, 12.29% , whereas at a height of 60 cm from the bottom the sample plastic had a percent degradadation 17.93 % and the highest degradation occurs at a height of 90 cm from the bottom, which is20.44% .

c. Degradability test under composting media

On composting media there are several parameters that must be evaluated to determine that compost was mature and stable. The parameters are temperature, moisture content, pH, volatile content, and C/N ratio. In this study the compos reaches a stable condition after 50 days. The average initial temperature of the compost pile was 28°C. The mean peak temperature obtained was 50°C on day 14. This gave an indication of the active decomposition phase consisting of high microbial activity in the organic matter. It should be noted that the temperature of the pile remained above 50°C for about 3 days. There was an abrupt decrease in temperature after day 6 due to the end of the active decomposition phase, as a result of

depletion in the amount of readily available organic matter for microorganisms or limiting amounts of one of the reactants. The temperature started to stabilize after day 20. The initial average moisture content of the pile was 52%, which increased to 60% on day 25 to reach a maximum of 62% on day 30. This increase was due to the decomposition process. Thereafter, a gradual decrease in moisture was noted, indicating water utilization by the microorganisms during the breakdown process. The moisture content decreased to about 55% on day 45, at which point it stabilized due to the absence of microbial activity and the initiation of compost maturation. Variation in volatile solids within the compost pile provides an indication of biological degradation over time. The volatile solids content decreased from 77% on day 1 to 62% on day 14, indicating that decomposition was taking place. An overall decrease of 45% in volatile solids content was obtained after 40 days of composting. At no time during the composting period did the pH go beyond the optimal pH range (6.2–8.5), implying that the conditions within the pile were always favorable for microbialactivity. The pH increased from 6 on day 1 to 8.5 on day 50. This indicated that microbial activity occurred effectively. The trends followed by the parameters indicated effective microbial activity; in other words, test samples were under an effective composting environment for successful and unbiased biodegradation to take place. Table 3 shows the percent degradation before and after composting.

Table 3 Percent Degradation of Plastics on Composting Media

Sample	Height from the bottom	Weight T_0(gram)	Weight T_{50}(gram)	% Degradation
@Ecoplas	30 cm	0.0519	0.0411	20.80
	60 cm	0.0512	0.0401	21.67
@Oxium	30 cm	0.0511	0.0468	8.410
	60 cm	0.0508	0.0442	12.99
HDPE	30 cm	0.0511	0.0510	0.190
	60 cm	0.0512	0.0510	0.390
Filter Paper	30 cm	00510	0.0000	100.0
	60 cm	0.0514	0.0041	92.02

There was no distinguishable cellulose filter paper left after 50 days of composting, implying that it was fully biodegraded (100%) and that the conditions required for biodegradation to occur in a composting environment were present. The weight of the @Oxium decreased by 8.41% at height of 30 cm from the bottom, and 12.99% at height of 60 cm from the bottom, implying that they did not fully degrade within the 50-day period and required more time for complete biodegradation as can be confirmed by the ISO 14852, which states that @Ecoplas degraded to about 20.8% at 30 cm from the bottom and 21.67 at 60 cm from the bottom after a period of 50 days under an aerobic composting (Table 3).

d. Degradability test under anaerobic media

For the anaerobic environment, biodegradability was determined in terms of biogas production. Figure 3 shows the cumulative variation in the volume of methane generated from anaerobic sludge IPAL Bojongsoang and Figure 4 from Sarimukti landfill soil during anaerobic digestion. A high rate of methane gas production was noted for filter paper and Ecoplas (a cumulative amount of 162 ml and 98 ml, respectively) until day 21 indicating high microbial activity, which correlated to the decrease in volatile solids. Figure 5 shows cumulative carbon dioxide from inoculum of anaerobic sludge IPAL Bojongsoang which were 34.32 mg for filter paper and 12.98 mg for Ecoplas, 4.27 mg for Oxium and 3.74 mg for HDPE. Figure 6 shows cumulative carbon dioxide from inoculum of Sarimukti lanfill soil which were 30.8 mg for filter paper, 9.94 mg for Ecoplas, 4.92 mg for Oxium and 3.34 mg for HDPE. Table 4 shows degradation of plastics on anaerobic conditions.

Table 4 Degradation of Plastics on anaerobic conditions

Media	Plastics	T_0 (gram)	T_{21} (gram)	% Degradation
Anaerobic Sludge WWTP Bojongsoang	@Ecoplas	1.089	0.872	19.92
	@Oxium	1.120	1.080	3.570
	HDPE	1,087	1.085	0.180
	Filter paper	1.023	0.012	98.82
Sarimukti Landfill Soil	@Ecoplas	1.018	0.843	17.19
	@Oxium	1.120	1.083	3.300
	HDPE	1.087	1.080	0.640
	Filter paper	1.023	0.102	90.02

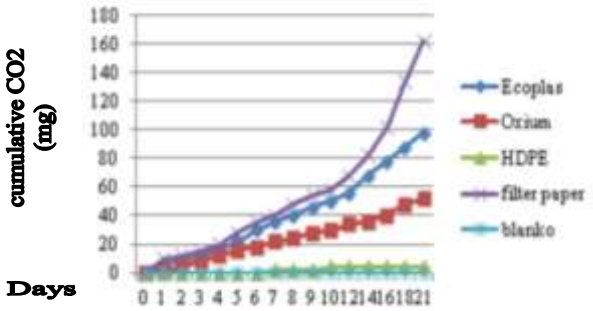


Figure 3 Cumulative of Methane on Anaerobic Sludge IPAL Bojongsoang

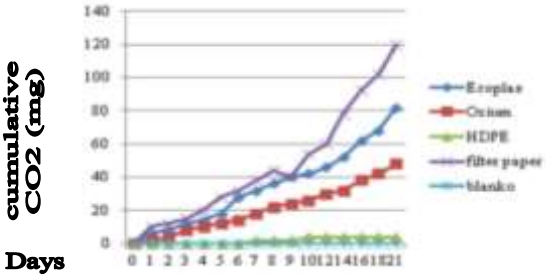


Figure 4 Cumulative of Methane on Sarimukti Landfill Soil

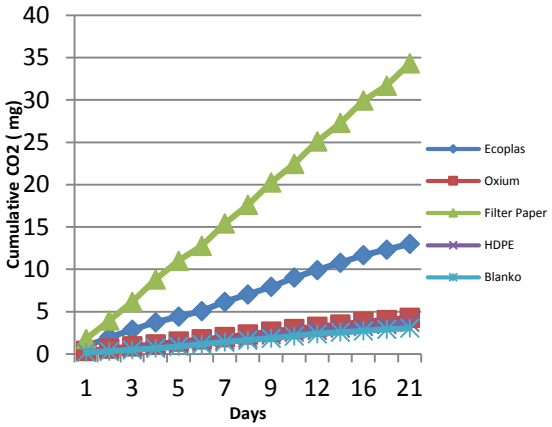


Figure 5 Cumulative of Carbon Dioxide on Anaerobic Sludge IPAL Bojongsoang

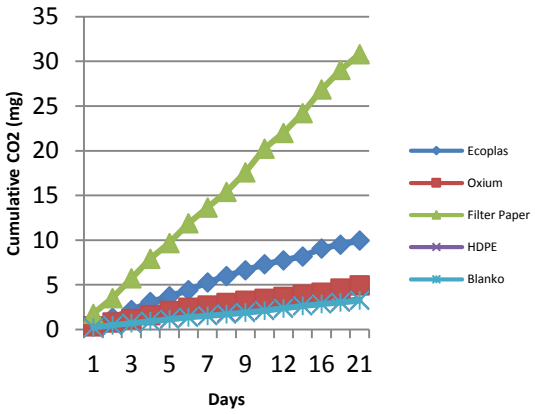


Figure 6 Cumulative of Carbon Dioxide on Sarimukti Landfill Soil

e. Degradability test under river media

The percentage weight loss that occurs in the river media is insignificant. This was because the testing method was done in batch conditions. According to research by Yunar (2011), if the testing method was done directly in the river for 6 weeks, then the @Ecoplas could be degraded100%. This was because in the river condition there were not only microorganisms, but also macro-organisms, such as fish, snails and other macro-organisms that could degraded the plastics. Table 5 showns the percent degradation of river media.

Table 5 Percent Degradation of Plastics on River Media

Sample	T (0) (gram)	T (7) (gram)	T (14) (gram)	T (21) (gram)	%degradation
@Ecoplas	0.2871	0.2820	0.2710	0.2320	19.19
@Oxium	0.3522	0.3500	0.3510	0.3170	9.990
HDPE	0.1342	0.1340	0.1339	0.1340	0.150

f. Tensile Strength Test

Tensile strength test performed in this study refers to the standard ASTM-D638. After the observation in several media such as soil media, waste media and the river water sample media, tensile strength test results that occur are shown in Table 6.

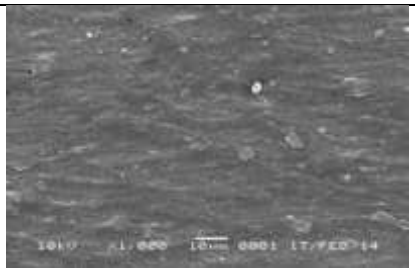
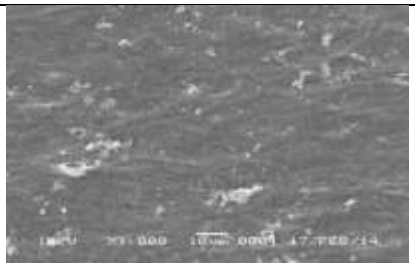
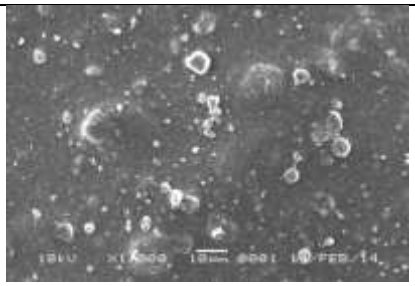
Table 6 Results of Tensile Strength Test

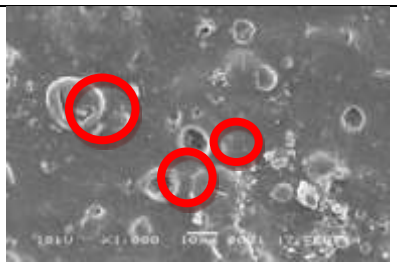
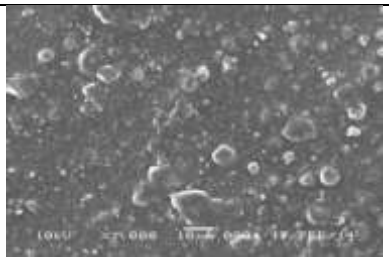
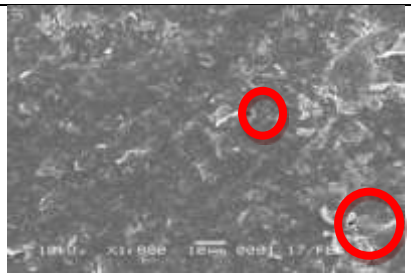
Sample	Media	Days	Tensile Strength Test (MPa)
@Ecoplas	Without Media	0	93.200
@Oxium			120.62
HDPE			134.52
@Ecoplas	Soil	90	70.200
@Oxium			100.62
HDPE			134.28
@Ecoplas	Waste	90	68.400
@Oxium			100.42
HDPE			133.88
@Ecoplas	River	21	88.820
@Oxium			112.62
HDPE			134.62

It can be seen from Table 6 that reduction value of tensile strength test happened in @Ecoplas and @Oxium. The reduced of tensile strength value because the constituent materials of plastic were degraded by microorganisms conditions that change the mechanical property of plastics, so that the value of tensile strength test also declined.

g. Scanning Electron Microscopy (SEM) Test

The SEM test in this experiments performed at a magnification of 1000X. The resulte of this SEM test were shown in Fig. 7, Fig. 8, Fig 9, Fig.10, Fig.11, Fig.12.

Sample	Media	Figure of SEM Test
HDPE	Soil Media T(0)	 **Figure 7 HDPE Sample on Soil Media T (0)**
HDPE	Soil Media T(90)	 **Figure 8 HDPE Sample on Soil Media T (90)**
@Ecopl as	Without Media T(0)	 **Figure 9 @Ecoplas on Soil Media T(0)**

Sample	Media	Figure of SEM Test
@Ecoplas	Soil Media T(90)	 **Figure 10@Ecoplas on Soil Media T(90)**
@Oxium	Without Media T(0)	 **Figure 11 @Oxium on Soil Media T(0)**
@Oxium	Soil Media T(90)	 **Figure 12 @Oxium Sample on Soil Media T(90)**

These are example of morphology plastics type @Ecoplas, @Oxium and HDPE before and after being tested on soil media for 90 days. It can be seen from Figure 7 and Figure.8, that there were no differences about HDPE Plastics before and after experiment. But for @Ecoplas and @Oxium, there were differences about before and after being tested. It can be seen from fig.9 and fig.12 that there were holes in @Ecoplas and @Oxium after being inserted on soil media for 90 days.

CONCLUSIONS

Biodegradable plastics degrade more than degradable plastics. No correlation of biodegradable plastics with the position of samples in the media. There is a correlation between degradable plastics with the position of samples in the media. The biodegradable and

degradable plastics weight reduction occurs more in waste landfill than in soil and aquatic water

References

Adam, S., Clark, S.D. 2009. *Landfill Biodegradation An in-depth Look at Biodegradation in Landfill Environments*. Bio-tec Environmental, Alburquerque & ENSO Bottles, LLC, Phoenix. p. 9-11.

Ahmann, D., Dorgan J.R. 2009. Bioengineering for Pollution Prevention through Development of Biobased Energy and Materials State of the Science Report, EPA/600/R-07/028. P.76-78.

Aini, R.N. 2013. Studi Awal Tingkat Stabilitas Sampah Kota Melalui Pengukuran Aktivitas Respirasi (RA4) (Studi Kasus : Kota Bandung, Jawa Barat). *Tugas Akhir*. Environmental Engineering Departement Institut Teknologi Bandung. Bandung.

Alyanak, D. 2004. Water Vapour Permeable Edible Membrane. *Thesis*. Biotechnology and Bioengineering Program Izmir Institute of Technology.

Anonim. Asian Biomass Handbook. The Japan Institute of Energy. 2008

Anonim (Eco Buddies). Biodegradable Plastic Technology from Ecoplas and Oxium. http://eco-buddies.com. 1 Februari 2014.

ASTM D 638-03. 2006. *Standard Test Method for Tensile Properties of Plastics*. United States.

ASTM D 5210-92. 2000. *Standard Test Method for Determining The Anaerobic Biodegradation of Plastic Materials in The Presence of Municipal Sewage Sludge.* United States.

Mohee, R. et al. 2008. *Biodegradability of Biodegradable/Degradable Plastic Materials under Aerobic and Anaerobic Conditions*. Department of Chemical and Environmental Engineering University of Mauritius. Mauritius.

Tchobanoglous, G., H. Theisen, dan S. A. Vigil. 1993. *Integrated Solid Waste Management: Engineering Principles and Management Issues*. McGraw-Hill. New York

Yunar, V. 2011. Evaluasi Biodegradabilitas Plastik Berbahan Dasar Campuran Pati dan Polietilen Menggunakan ASTM G21-09, Uji Mikroorganisme dan Uji Lapangan. *Skripsi*. Program Studi Teknik Lingkungan Universitas Indonesia. Depok.