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Article

Determination of Biodegradability of Polyethylene-based Waste Material Melt-Blended with Gum Arabic

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Abstract: In this study, gum Arabic and low density polyethylene have been used to form polymer blend. Low density polyethylene was melt/blended together with the gum Arabic using different weight percent mixing formulations namely PE_9GA_1, PE_8GA_2, PE_7GA_3, PE_6GA_4, PE_5GA_5, and PE_{10} respectively. Physical Characterization (such as water uptake, thickness swelling, chemical resistance, and flammability) shows that the best results were exhibited by the Polyethylene (6g) and gum Arabic (4g) i.e. (PE_6GA_4) formulation. Additionally this formulation revealed that more than 43% of the polymer blend was biodegraded through soil burial approach within one month. This research implies that incorporating gum Arabic into polyethylene could potentially improve its biodegradation.

Keywords: polyethylene, gum arabic, biodegradation, polymer blend

1. Introduction

Polymers are large molecules formed by the union of identical monomers which may be natural (Cellulose or DNA), or synthetic (nylon or polyethylene). In earlier times, before the making of synthetic polymer, what the world used to know was rubber. Natural rubber, as it was then known, was of limited usefulness to the industries (Browne et al., 2011). Polyethylene is formed through addition polymerization reaction. This occurs by a sequential addition or linking of a large number of unsaturated molecules (the monomer unit – ethene).

Polyethylene is a waxy, translucent, flexible thermoplastic. It is one of the lightest plastics having a specific gravity of 0.92 - 0.93.

Below 60˚C, polyethylene is insoluble in all solvents and is resistant to the action of most chemicals other than strong oxidizing acids. However, above 115˚C, the polymer changes from a clean solid to a low viscosity melt. At this temperature and above, exposure to air causes relatively extensive oxidative degradation, unless antioxidants are included in the polymer (Agamuthu, 2000).

A number of factors can initiate the degradation of polyethylene, such as ultra-violet light, heat, oxygen and film stress (such as pulling and tearing) (Aswale, 2010).

Polyethylene is probably the polymer seen most in the world. This is because polyethylene is cheap, safe, harmless, and stable in most environments and easily processed. The use to which polyethylene is put depends on whether it is low-density or high-density type. Low- density polyethylene is used as kitchen utility ware, in the manufacture of toys, process tank liners, closure packages, sealing rings and battery parts. Other uses are as squeeze bottles for packaging and containers for drugs. The film is used as wrapping materials for food, fruits and clothe.

Polyethylene is also used in covering wires and cables because of its high insulating properties. It is also molded into pipes used in transporting chemicals, natural gas and water for various uses. High density polyethylene is used in making refrigerator parts, pipes, defroster, heater ducts, sterilizable house wire and hospital equipment and hoops.

This is attributed to its higher resistance to high temperature(Aswale, 2010). In Nigeria, waste disposal is very poor. Most of the polyethylene wastes originate from consumption of products packaged in polyethylene sachets, bags or other containers, (Aswale, 2010).

Xenobiotic such as polyethylene are chemically synthesized organic compounds, most of which do not occur in nature. They are compounds that are foreign to a living organism. Where these compounds are not easily recognized by existing degradative enzymes, they accumulate in soil and water. Indiscriminate dumping of the so called ‘pure water sachets’ on roads, and drainage channels in Nigeria cause blockage of such channels and flooding of the environment during rainy season. In a bid to minimize these effects, burning of polyethylene waste materials has been adopted as a management strategy(Browne *et al*., 2011).

This method in effect, constitutes a greater part of environmental pollution with many greenhouse effects. Gases such as carbon dioxide, carbon monoxide and subsequently sulphur and nitrogen oxides are released into the atmosphere giving rise to acid rains, ozone depletion and global warming. Synthetic fibres like polyethylene and polypropylene are practically non-degradable. Although, more organisms are being described as being able to degrade these anthropogenic molecules, some xenobiotics have been shown to be unusually recalcitrant (Esteve-Nenez*et al*., 2001). The ability of etaliciseto degrade organic pollutants has been reported in earlier studies (Nwachukwu*et al*., 1999; Nwachukwu, 2000). Etalicise are known to have strong ability to resist toxic substances, including heavy metals such as mercuric compounds and disinfectants (Baron *et al*, 1994).

The problem of pollution caused by polyethylene waste materials cannot be overemphasized. The aim of this study was therefore, to enhance the biodegradation of polyethylene by incorporation of gum Arabic through melt-blending process.

Biodegradation is necessary for water-soluble or water-immiscible polymers because they eventually enter streams which can neither be recycled nor incinerated. It is important to consider the microbial degradation of natural and synthetic polymers in order to understand what is necessary for biodegradation and the mechanisms involved. This requires understanding of the interactions between materials and microorganisms and the biochemical changes involved. Widespread studies on the biodegradation of plastics have been carried out in order to overcome the environmental problems associated with synthetic plastic waste, (Lopez-Marín J. and Marín I, 2011).

Low density polyethylene is one of the major sources of environmental pollution. The use of polyethylene growing worldwide at a rate of 12% per year and about 140 million tons of synthetic polymers are produced worldwide each year, (Browne *et al*., 2011). With such a large amount of polyethylene gets accumulated in the environment.

Gum Arabic is found in nature as a mixed calcium, magnesium and potassium salt of a polysaccharidic acid, it consists of six carbohydrate moieties: galactopyranose, arabinopyranose, arabino-furanose, rhamnopyranose, glucuropyranosyaluronic acid and 4-O-methyal glucuropyranosyaluronic acid. Gum Arabic contains small proportion of protein as an integral part of the structure.

2. Materials and Methods

2.1.Materials

Low density polyethylene (LDPE) which is the major cause of environmental pollution and also Gum Arabic was used for the study.

Table 1: Materials and Manufacturers

S/N	Materials	Manufacturer(s)
i.	Weighing balance	W12001NFE
ii.	Gum Arabic	
iii.	Waste polyethylene bags (pure water sachets)	Namaki enterprises
iv.	Stainless steel	Chiarxer company china
v.	Rubber container	Dala plastic company
vi.	Distilled water	
vii.	Hot plate	DB-24
viii.	Scissors	
ix.	Detergent	Klin
x.	Vanier caliper	Diamond measuring ltd
xi.	Beaker	Pyrex
xii.	Measuring cylinder	Gaeg process glass India
xiii.	Stop watch	Diamond stop watch

2.2. Reagents

Chemicals, reagent and their manufacturers are listed below.

Table 2: List of Chemicals and Reagent their Manufacturers

S/N	Reagent	Chemical formula	Manufacturer(s)
i.	Nitric acid	HNO_3	Kermel
ii.	Sulphuric acid	H_2SO_4	Kermel
iii.	Hydrochloric acid	HCl	BDH
iv.	Reagent bottle		White glass bottle

2.3. Sample Collection

The sample of waste polyethylene (pure water sachets) was collected from different location in Sabongari area Jega, Kebbi State and the Gum Arabic was purchased from Jega central market in a sterilized polythene bags, and the sample was taken to Kebbi State University of Science and Technology, Aliero (KSUSTA) Chemistry Laboratory for identification, after which it was kept in the Laboratory for further analysis.

Figure 1: Sample of Gum Arabic

Figure 2: Sample of waste polyethylene bags

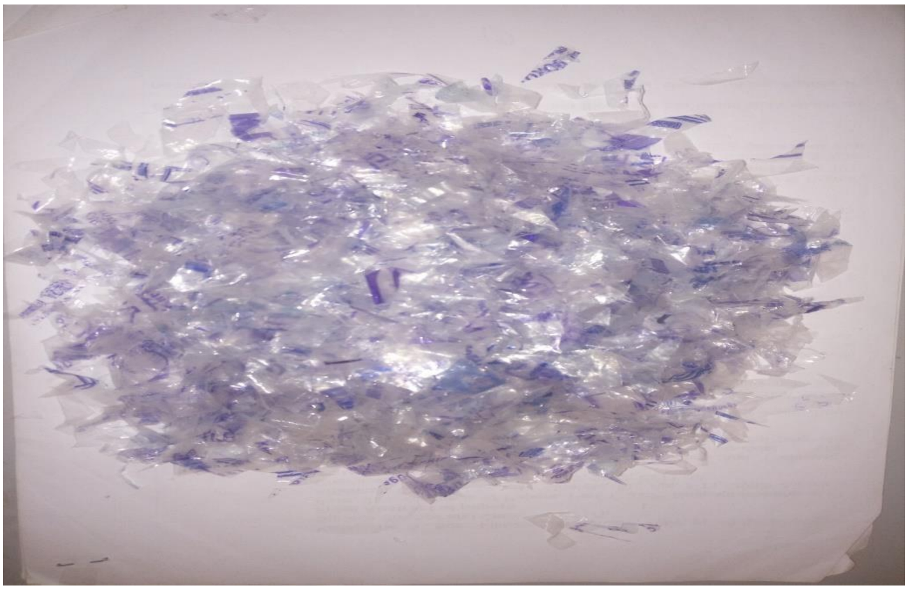

Figure 3: Sample of waste polyethylene in small pieces

2.4. Sample Preparation

The sample were prepared by washing the waste polyethylene bags with detergent and water, Gum Arabic also washed with distilled water and dried at room temperature. The waste polyethylene bags were cuts into smaller pieces to increase surface area. The Gum Arabic was melted by heating it at high temperature using hot plate in a small stainless steel, when it melted the polyethylene was added and melt-blended together with the gum Arabic. The various mixing formulation include, 9g of polyethylene is blended with 1g of gum Arabic (PE_9GA_1), 8g of polyethylene with 2g of gum Arabic (PE_8GA_2)polyethylene 7g with gum Arabic 3g (PE_7GA_3), polyethylene 6g blended with gum Arabic 4g (PE_6GA_4), and polyethylene 5g blended with gum Arabic 5g (PE_5GA_5) respectively as shown in table 3.

Table 3: Sample formulation of Low density polyethylene (LDPE) and Gum Arabic (GA) of the blends

Sample code	**LDPE (g)**	**GA (g)**
PE_9GA_1	9	1
PE_8GA_2	8	2
PE_7GA_3	7	3
PE_6GA_4	6	4
PE_5GA_5	5	5

Figure 4: Polyethylene/Gum Arabic blend (8g-2g)

The melt-blends were formed by heating at temperature ranging from 115ºC to 160ºC. After blending, the sample is kept under room temperature to cool and solidity. Then, the sample were cut at 10mm by 5mm to make specimen samples. (Fig.5). the samples thickness were measured using digital vernier caliper.

Figure 5: Length of the above samples is 10mm by 5mm

2.4. Characterization

2.4.1. Soil burial test

Soil burial method was performed to monitor the weekly weight loss of the polymer samples during biodegradation. Loamy soil was used to analyzed the biodegradation of polymer blend, were five (5) samples specimen were inserted and buried in the soil, the soil contain small amount of moisture which can help for the degradation process and also the bacteria presence in the soil require water to survive, After every 7 days (one week), the samples were removed and their weights were measured and recorded.

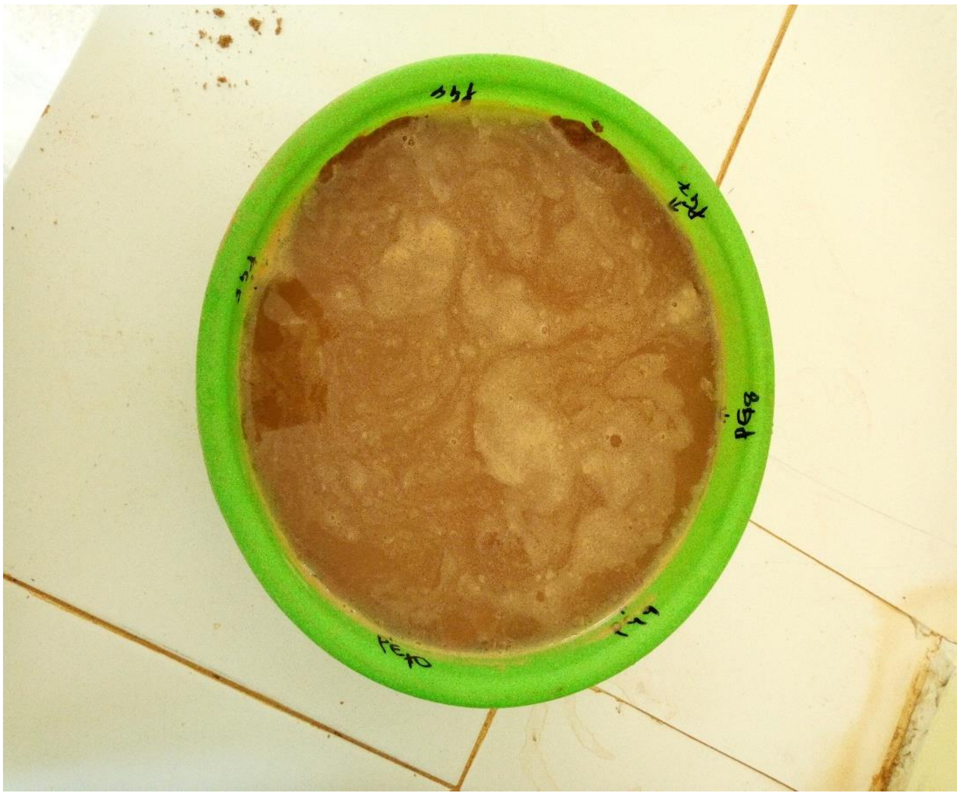

Figure 6: Soil burial test

2.4.2. Dimensional stability test (water uptake and thickness swelling)

The sample specimens were weighed (W_1) placed into a beaker of distilled water for 24 hours to test their water absorption and degradation potentials. Therefore, six (6) beakers were used for the experiment. The first one contain the sample of PE_9GA_1, the second beaker carries the mixture of PE_8GA_2, the third contains PE_7GA_3, the fourth beaker contains PE_6GA_4, fifth contains PE_5GA_5 while the last beaker contains PE_{10}. After 24 hour, the samples were removed from the beaker and cleaned dried with tissue papers. The thickness and weights were re-measured (W_2) immediately from the beaker by vernier caliper and weighing balance respectively. The water uptake and thickness swelling were calculated using the following equation 1 and 2.

$$\text{Water Uptake (\%)} = \frac{W2(g) - W1(g)}{W1(g)} \ x\ 100 \quad \ldots\ldots\ldots\ldots\ldots(1)$$

$$\text{Thickness Swelling (\%)} = \frac{T2(mm) - T1(mm)}{T1(mm)} \ x\ 100 \ldots\ldots\ldots\ldots\ldots\ (2)$$

Where W_1= Initial Weight T_1= Initial Thickness

W_2 = Final Weight T_2= Final Thickness

2.4.3. Chemical resistance test

The chemical resistance test was used to determine whether the sample of polyethylene incorporated with gum Arabic is resistance to chemical (acid) or not. Nitric acid (HNO_3), Sulphuric acid (H_2SO_4) and Hydrochloric acid (HCl). A 60% concentration was used for each of the acid. The samples were weighed (W_1) and placed into the beaker with the dilute acid for 24hours. After 24hours the samples were removed and reweighed (W_2). The gain/loss in weights of the samples was calculated using equation 1 above.

Figure 7: Chemical resistance test

2.4.4. Flammability test

The sample of the polyethylene blend with gum Arabic were cut into 20mm by 5mm, reference points were marked on each specimen having initial 0.00 and final at 2.12, each sample is set on fire to determine the time at which each sample will burn.

3. Results and Discussion

3.1. Dimensional Stability

Thickness Swelling and Moisture uptake.

3.1.1.Thickness swelling

Thickness swelling involved the measurement of the sample using vernier caliper to measure the thickness of each sample. Pure polyethylene was measured 3.07% before putting it inside water and its final reading was 3.07 which show that no change has occurred. The sample of PE_5 GA_5 has a change of 9.96%, PE_6 and GA_4 has 10.70%, PE_7 and GA_3 the thickness of 8.77%, polyethylene 8g with gum Arabic 2g contain the total thickness of 5.12%, also the polyethylene 9g with gum Arabic 1g have the thickness of 4.42%. This shows that the polymer of 6g blend with gum Arabic of 4g have the highest thickness swelling among others. Because the sample (gum Arabic) is hydrophilic, i.e. absorb more water and less in weight compare to other samples. This is also as a result of higher ratio of gum Arabic in PE_6GA_4 then corresponding PE_9GA_1, PE_8GA_2, and PE_7GA_3. While pure polyethylene is hydrophobic. The results of the thickness swelling are shown in table 4 below.

Table 4: Results of the thickness swelling for the samples

S/N	Sample Code	T_1 (mm)	T_2 (mm)	(%)
1	PE_9GA_1	3.56	3.40	-4.49
2	PE_8GA_2	2.54	2.40	-5.11
3	$PE_7 GA_3$	2.74	2.50	-8.76
4	$PE_6 GA_4$	2.53	2.26	-10.67
5	$PE_5 GA_5$	2.69	2.43	-9.97
6	PE_{10}	3.70	3.70	0.00

3.1.2. Moisture uptake

Moisture uptake involves the weight of each sample after putting the sample inside water for about 24hours. Sample of pure polyethylene 10g has initial 0.20 and the final is 0.20 which means there is no change in the weight of the sample; therefore, it contains 0.00%. polyethylene 9g in cooperate with gum Arabic 1g have initial weight 0.30g and 0.24 as final weight, it totally contain 20.00%, PE 8g and GA2g have the water uptake of 14.29%, PE 7g and GA 3g have 30.00%, PE 6g and GA4g 20.00%, and finally polyethylene 5g with gum Arabic 5g have water uptake of 41.67%. This shows that polymer 5g with gum Arabic 5g is (hydrophilic) having the highest water uptake. This is because PE_5GA_5 contain higher ratio of gum Arabic than corresponding PE_9GA_1, PE_8GA_2, PE_7GA_3, and PE_6GA_4. While pure polyethylene is hydrophobic. The results of the moisture uptake are shown in table 5 below.

Table 5: Results of the moisture uptake for the samples

S/N	Sample Code	W_1(g)	W_2(g)	(%)
1	PE_9GA_1	0.30	0.32	6.67
2	PE_8GA_2	0.14	0.12	-14.29
3	PE_7GA_3	0.20	0.14	-30.00
4	PE_6GA_4	0.20	0.16	-20.00
5	PE_5GA_5	0.24	0.14	-41.67
6	PE_{10}	0.20	0.20	0.00

3.1.3. Biodegradation

The biodegradability result presented in Table 6 revealed that Polyethylene 9g with gum Arabic 1g, in the first week there is no change, in the second week there is a little change to 0.26g, in the third week the weight of the sample is 0.22g and lastly the fourth week reads 0.18g. PE 8g with GA 2g the first week is stagnant no change, the second week and the third week reads 0.12g, while the fourth week reads 0.10g. PE 7g with 3g the first week is 0.20g as initial, the second week is 0.18g, the third week is 0.16g and finally the fourth week reads 0.14g. PE 6g with GA 4g first and second week remain the same 0.20g, in the third week it reads 0.16g and the fourth week reads 0.14g. PE 5g with GA 5g in the first and the second week there is no change that occurs, the third week the sample change to 0.14g, and finally the fourth week read 0.12g. And Pure Polyethylene 10g (PE_{10g}) there is no change from the first week up to fourth week the sample remains the same 0.20g.The biodegradability results are shown in table 6 below.

Table 6: Soil burial test results for biodegradability

S/N	Sample Code	INITIAL	1ST Week	2nd Week	3rd Week	4th Week	MEAN
1	PE_9GA_1	0.30	0.30	0.26	0.22	0.18	0.25
2	PE_8GA_2	0.14	0.14	0.12	0.12	0.10	0.12
3	PE_7GA_3	0.20	0.20	0.18	0.16	0.14	0.18
4	PE_6GA_4	0.20	0.20	0.20	0.16	0.14	0.18
5	PE_5GA_5	0.22	0.22	0.20	0.14	0.12	0.18
6	PE_{10}	0.22	0.22	0.22	0.22	0.22	0.22

3.1.4. Chemical resistance test

This chemical resistance test is carried out to determine if polymer in cooperated with gum Arabic can resist chemicals or not. Three chemicals were used. (Nitric acid, Sulphuric acid and Hydrochloric acid). The first sample shows that PE 6g GA 4g, PE 8g GA 2g has no change with nitric acid, it's 0.18g and 0.26g respectively, while the pure polyethylene 10g has changed with nitric acid from 0.22g to 0.14g. Only pure polyethylene change with nitric acid. For the Sulphuric acid, the PE 6g GA 4g changes from o.18g to 0.20g, PE 8g GA 2g also changes from 0.20g to 0.22g while the pure polyethylene 10g change from 0.22g to 0.14g. Hydrochloric acid, PE 6g with GA 4g remain 0.18g, PE 8g with GA 2g also remain 0.20g while the pure polyethylene change from 0.20g to 0.16g. The chemical resistance test shows that pure polyethylene 10g change in all of the acids while PE 6g GA 4g and PE 8g GA 2g change only in sulphuric acid. The chemical resistance test results are shown in table 7 below.

Table 7: The chemical resistance test results for the samples

S/N	Sample Code	Reagent	W_1 (g)	W_2 (g)	$\frac{W2 - W1}{W1}\ x\ 100(\%)$
1	$PE_6\ GA_4$	HNO_3	0.18	0.18	0.00
2	PE_8GA_2	HNO_3	0.20	0.20	0.00
3	PURE PE_{10}	HNO_3	0.20	0.14	-30.00
4	PE_6GA_4	HCl	0.18	0.18	0.00
5	PE_8GA_2	HCl	0.20	0.20	0.00
6	PURE PE_{10}	HCl	0.20	0.16	-20.00
7	PE_6GA_4	H_2SO_4	0.18	0.20	11.11
8	PE_8GA_2	H_2SO_4	0.20	0.22	10.00
9	PURE PE_{10}	H_2SO_4	0.20	0.14	-30.00

3.4.5. Flammability test

The sample were cut and set on a fire, to determine rate at which all the samples burn. The sample of pure polyethylene 10g (PE_{10}) was set on fire and burn at 19mm/27sec, (PE_9GA_1) burn at 17mm/49sec, (PE_8GA_2) burns at 15mm/43sec, (PE_7GA_3) burns at 13mm/38sec, (PE_6GA_4) burns at 11mm/31sec, and (PE_5GA_5) burns at 9mm/26sec. The flammability test results are shown in table 8 below.

Table 8: The flammability test results for the samples

S/N	Sample Code	Horizontal Burning (mm/min)	Time (S)
1	PE_9GA_1	17	49
2	PE_8GA_2	15	43
3	PE_7GA_3	13	38
4	PE_6GA_4	11	31
5	PE_5GA_5	9	26
6	PURE PE_{10}	19	27

4. Conclusion

Polythene is one of the major threats to the environment. Research has been initiated to find out the solution for effective degradation LDPE and some plastics. It is now really a mess for mankind. In this present work low density polyethylene was corporate into gum Arabic to enhance biodegradation. The microorganisms associated with the Samples were identified through soil burial test which revealed the presence of both bacteria and fungi in large number. These microorganisms were used for future degradation process. The results are sensitive and also affect various factors, particularly the consortia of microorganisms used. After the inoculation of LDP in microbial consortium the film has turned from smooth to rough with cracking. This occurred be due to the present of gum Arabic met-blended with polyethylene and also compounds secreted extracellular by the microbes that may break the complex molecular structure of LDP. From all the results obtained, it is clear that further biodegradation studies of polyethylene incorporation with gum Arabic will reduce rate of environmental pollution, flooding, and agricultural effect. Also, CO_2, CH_4, and water are produced in biodegraded polyethylene corporate with gum Arabic.

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