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Characterization of Recycled Plastics for Structural Applications

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ABSTRACT

This work is designed to study experimentally, the mechanical behaviour of various waste plastic materials in Ghana. The materials studied were low density polyethene (LDPE), high density polyethene (HDPE) and polyethylene terephthalate (PET). The extrusion process was used to recycle the waste plastic into pellets and injection moulding method used to prepare the pellets into the test specimen. Tensile and bend tests were performed and the results were used to determine the properties of the materials under study. The force and deflection/extension plots obtained, obeyed Hooke's law. From the results, it was observed that, the percentage elongation of the used sachet water plastic (PET) and the black plastic (HDPE) fall within the range of the virgin material whilst the used white plastic (LDPE) falls outside the range. However, the young's moduli and the ultimate strengths of the used plastic materials, differ from those of the virgin materials. The percentage ration of the used and the virgin were then computed to determine their use in engineering field. It was established that, for the ultimate strength, the percentage ratio for HDPE, PET and LDPE were 68.27%, 65.62% and 64.58% respectively. The corresponding moduli of elasticity of the materials as a percentage of the virgin materials were obtained as 48.20% for HDPE , 8.45% for PET and 49.10% for LDPE . The Ultimate tensile strength ranges from the literature, compared with that of some selected plastics commonly used in Ghana: HDPE, PET and LDPE were 68.2694%, 44.922% and 64.576% respectively. Also, the corresponding modulus of elasticity of the materials as a percentage of the virgin materials was obtained as 69.499% for HDPE, 6.684% for PET and 48.68% for LDPE. It was further observed that the percentage elongations of all the materials were within the range as the original material. Hence it can be concluded that HDPE would be a good material to be used for engineering application, for example, as a composite matrix for the construction of wind turbine blade.

Keywords: *Plastic, Tensile Test, Characterization, Bending Test, Modulus of Elasticity*

1. INTRODUCTION

Over the past decade, generation of municipal solid wastes (MSW) in developing countries has been on the increase, and in Malaysia to be specific, it had increased more than 91% (Periathamby, 2009; Mohd and Mashitah, 2013). The most preferred disposal method of MSW, in most developing countries, is through landfilling. Municipal solid waste management (MSW) becomes a great challenge in development plans throughout the world, especially in rapidly growing cities (Mohd and Mashitah, 2013).

Ghana has waste management problems that extend from local to the national level. These problems are made complicated by population pressures in the heavily populated cities of which Accra and Kumasi are the most prominent. Solid waste management is an essential factor contributing to the health, productivity and welfare of the people of Ghana.

The rate of waste generation in Ghana was 0.47 kg/person/day, which translates into about 12,710 tons of waste per day per the current population of 27,043,093. The breakdown, nationally, was biodegradable waste (organic and paper) 0.318 kg/person/day, and non-biodegradable or recyclables (metals, glass, textiles, leather and plastics) was 0.096 kg/person/day, while inert and miscellaneous waste was 0.055 kg/person/day (Miezah et al., 2015).

Since the turn of the new millennium, there has been a rise in the proportion of plastic waste in the municipal solid waste (MSW) in Ghanaian cities, including the Kumasi metropolitan area. (Owusu-Sekyere et al., 2013). This has been as a result of a steady increase in the use of plastic products for more hygienic mode of packaging food, beverages, water and other products. However, the packaging revolution has not been backed by a correspondingly appropriate plastic waste management policy, and therefore has left many cities in Ghana littered with plastic waste; creating disgusting visual nuisance and public health problems. (Owusu-Sekyere et al., 2013). It is worth noting that low sanitation levels on the African continent are significantly influenced by poor waste management practices especially dumping of waste in water bodies and uncontrolled dump sites. As a result of plastic's resilience against degradation and its proliferation in industry, the issue of plastic pollution has evolved to become a threat to global ecology (Webb, 2013).

The ability to reduce municipal solid waste (MSW) by volume and at the same time use it to generate heat and electricity, has made the use of combustion/incineration methods rather than landfill methods more and more important (Yang et al., 2002). Incineration, however, does not play a significant role in solid waste management in Ghana and it is primarily used for the treatment of healthcare waste. On the other hand recycling of plastics after sorting such waste out, is becoming even more popular. Although plastics are not intrinsically dangerous, they take up a huge amount of space in landfills and thus go to waste even though they are made from fossil fuel which is a non-renewable resource (Selinger, 1986). Using plastic packaging to enhance the future availability of recycled plastics as a sustainable material option is laudable. It is therefore important that, where possible, plastics are recycled. The recycling of plastics is carried out in a five step process. They are Plastics collection, Manual sorting, Chipping, Washing and Pelleting by melting it down and extruding into small pellets ready for reuse. (Selinger, 1986)

Polymers have received much attention in an attempt to synthesize organic polymers as alternative to conventional inorganic materials, due to their unique properties, such as low density, ability to form intricate shapes, versatile electric properties and low manufacturing cost (El-Khodary et al., 2008). The widespread applications of polymers or plastics are not only due to their favourable mechanical and thermal properties, but also mainly due to the stability and durability. Among the plastics the most easily recycled ones are Polyethylene Terephthalate (PET) and Polyethelene. The most commonly used non-degradable solid waste is polythene. (Kavitha et al., 2014).
The most widely used types of polythene are the low density polyethelene (LDPE) and high density polyethelene (HDPE). LDPE resins are thermoplastics made from ethylene with the repeating unit (–CH2–CH2–)n. They are stiff plastics but lack hardness and brittleness and have a somewhat waxy feel. The 2006 world production of LDPE was estimated at 17.3 million metric tons (38.1 billion pounds) (The Dow Chemical Company, 2014). It is a polyethelene with a density less than 940 kg/m^3 and is produced by a high pressure process. (Plastics Europe, 2008). HDPE, however, is usually regarded as a polyethylene with a density greater than 940 kg/m^3. It is produced in low pressure reactors. (Plastics Europe, 2008). The 2007 world production of HDPE was estimated to be 29.8 million metric tons (65.7 billion pounds) (The Dow Chemical Company, 2014).

The density of polyethylene depends on the proportion of crystals within its mass. Crystals, which are a result of the layering and close packing of polyethylene molecules, are denser than the tangled, disordered arrangement of molecules in the amorphous regions. (Gabriel, 2009). Copolymers are often used to create and control the formation of side branches. Homopolymers, with densities of 0.960 g/cm^3 and above, are produced without copolymers and experience very little branching. Butene, hexene or octene are added to make a copolymer to reduce the density. Butene adds branches two carbon units long; hexene, four carbon units long; and octene, six carbon units long. The greater the length of the branched carbon chains, the lower the final density. (Gabriel, 2009). ASTM D 3350 classifies polyethylene by density as follows: high-density polyethylene (HDPE) are polyethelene with densities from 0.941 g/cm^3 to 0.965 g/cm^3, and low-density polyethylene (LDPE) are polyethelene with densities from 0.910 g/cm^3 to 0.925 g/cm^3). (Gabriel, 2009).

Another easily recycled polymer, Polyethylene Terephthalate (PET) is a crystallizable polymer. It is either in the semi-crystalline state or in the amorphous state. The levels of crystallinity and morphology significantly affect the properties of the polymers (DEMİREL et al., 2011). Polymers with high crystallinity have a higher glass transition temperature Tg (Tg is 67 °C for amorphous PET and 81 °C for crystalline PET) and have higher modulus, toughness, stiffness, tensile strength, hardness and more resistance to solvents, but less impact strength (DEMİREL et al., 2011).
A human exposure threshold value has been developed to define exposure level for chemicals with structural alerts that raise concern for potential genotoxicity below which the probability for adverse effect for human health is negligible. This threshold is 0.15µg/person/day, for a person of 60 kg body weight, corresponding to 0.0025 µg/kg bw/day (Kroes *et al.*, 2004). Generally, this threshold value is low enough to address concern over all toxicological effects (Anadón et al., 2011).

Products manufactured from recycled plastics can result in 50-60% capital saving as compared to that manufactured from virgin resin (Sinha et al., 2008). In-spite of that, Welle noted that the main driving force in PET recycling is not cost reduction, but the business sector's embracing of sustainability ethics and the public's concern about the environment (Welle, 2011). A study of the Gross Recycling Rates of plastic bottles, mainly PET, has seen a consistent and steady increase from 19.6% to 31.2% from 2003 to 2013, in the USA (NAPCOR, 2014).

History may view plastics as one of the most important technical developments of the 20th century (Hannequart, 2004**).** By using recycled PET as a sustainable material option for the packaging of manufactured products, greenhouse gas emissions and landfill waste disposal is reduced (Aceves, 2014).

In Europe, the growth of the plastics industry has a multiplier effect on numerous important sectors of their economy. The plastics industry is a key enabler of innovation of many products and technologies in other sectors of the economy. Innovation and growth in Europe depend mainly on manufacturing, in particular the plastics industry (Plastics Europe, 2015).

Many consumers are unaware of the significant usefulness, demand, and value of recycled plastic HDPE and PET; this is a barrier which education campaigns can help to break. Another barrier to increased recycling is lack of sufficient access to recycling collection opportunities for products used away from home (ACC & APPR, 2013).

Plastic waste takes a longer time to decompose and considered to be non-biodegradable. They can stay in the environment for long period of time causing problems to the environment and to the health of the society. Petroleum plastics are the non-biodegradable synthetic polymers that accumulate at the rate of 25 million tons per year, part of that contaminating the soil and water (Eubeler et al. 2010). Eventhough they are generally considered non-biodegradable, they degrade to some small extent. This relatively small biodegradation is characterized by weight loss (Kyaw et al. 2012), and the change in mechanical and chemical properties (Roy et al. 2008). Hence, the objective of this work is to characterize and select the plastic material which retains the best mechanical properties after usage for reuse.

2. MATERIALS AND METHODS#

2.1. Materials

Three types of plastics materials were selected for this study. These include plastic high density polyethene (HDPE), locally called black polyethene bag, polyethylene terephalate (PET), locally called sachet water plastic and lastly, low density polyethene (LDPE), locally called the white polyethene bag. The properties of the three materials are tabulated and presented in Table 1.

Table 1 Properties of the Plastic Materials

Material	Young's Modulus (GPa)	Ultimate Strength (MPa)	Elongation (%)	Glass Transition Temperature (ºC)	Composition
High density polyethene	0.8	26-33	150	130	$(C_2H_4)_n$
Polyethylene terephalate	0.11-0.45	25-May	500	80	$(C_2H_4)_n$
Low density polyethene	2-2.7	55	125	250	$(C_{10}H_8O_4)_n$

2.2. Preparation of Samples

The materials were first collected and each sample collected cut into pieces, as illustrated in Figure 1. After cutting, the pieces were fed into an extrusion machine to be extruded as shown in Figure 2.

Figure 1: The cutting process of the various plastics

The extrusion machine was started and the melting zone was allowed to heat up to a temperature of 180ºC, before the cut pieces were fed through the hopper into the feeding zone. The

pieces were then compressed by a screw action, powered by a motor. After compression, the pieces are melted in the melting zone and exit in a form of spaghetti-like strips as shown in Figure 3b.

Figure 2: Materials being fed into the machine

After the extrusion process, the spaghetti-like strips are further chopped into pellets with a knife as shown in Figure 3.

Figure 3: Output of the extrusion process: (a) molten extrudate (b) solidified extrudate (c) and (d) pelletized extrudate.

The injection moulding machine was used to produce the test specimen. During this process, the heating chamber was allowed to warm-up till the melting temperature of the pellets was attained before feeding the pellets through the hopper into the machine. The molten material was then channelled into the specimen's mould and allowed to take the shape of the mould under pressure until solidification. The solidified specimen was then ejected. The processed tensile test specimen are shown in Figure 4.

Figure 4: Processed tensile test specimen.

2.3. Tensile Test

The objective of this experiment was to obtain the mechanical properties for the three (3) plastic materials under study. Seven (7) samples of specimen were used for each type of material for the test. The specimen was first griped firmly in the jaws of the tensile test machine. The wheel was turned to drive the rack and pinion system allowing the griping part to accommodate the specimen. The specimen was then strained to an extension of 1.27 mm (0.05 inches) and the corresponding force for this extension, was determined by a balance system attached to the machine. The extension and its corresponding force were recorded. The extension was increased steadily, while recording different extensions and their corresponding forces, until the material failed. This procedure was repeated for the remaining specimen for all the three (3) different materials and the results were recorded.

The load/displacement data were analysed and transformed into stress and strain, using Equations 1 and 2 respectively. The plot of stress and strain was used to determine the modulus of elasticity with Equation 3 and the ultimate stress.

The stress is given by

$$\sigma = \frac{P}{A} \quad (1)$$

and the strain is

$$\varepsilon = \frac{e}{l} \quad (2)$$

The modulus of elasticity E is

$$E = \frac{\sigma}{\varepsilon} \quad (3)$$

3. RESULTS AND DISCUSSION

3.1 Tensile Properties

A stress-strain curves were drawn as shown in Figure 5, the stress was calculated using the original cross-sectional area of the test piece. From the stress-strain curve, the ultimate stress and Young's modulus, E, were obtained.

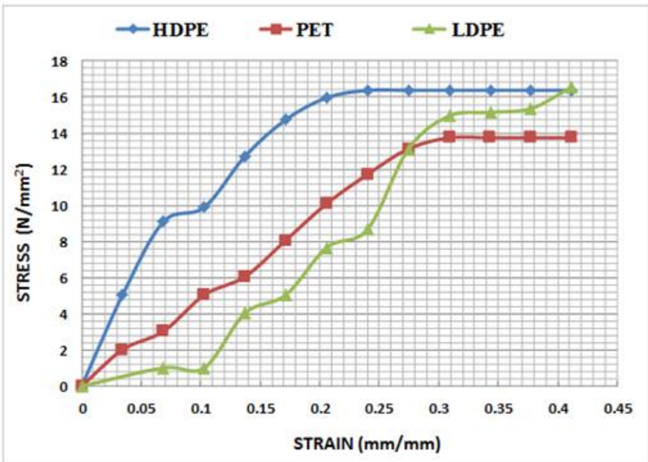

Figure 5: Plot of Stress-strain curves for the three plastic materials

Using Equation 3 and the plots of stress-strain for the three different plastic materials, the moduli of elasticity were obtained and the results tabulated and presented in Table 2.

The ultimate strengths of the three plastic materials were determined from the plots and the results tabulated and presented in Table 3.

Table 2 Modulus of Elasticity of the Specimen

SAMPLE	MODULUS OF ELASTICITY (E)/ GPa		
	HDPE	PET	LDPE
1	$E_1 = 0.066$	$E_1 = 0.048$	$E_1 = 0.053$
2	$E_2 = 0.067$	$E_2 = 0.053$	$E_2 = 0.058$
3	$E_3 = 0.068$	$E_3 = 0.048$	$E_3 = 0.047$
4	$E_4 = 0.065$	$E_4 = 0.049$	$E_4 = 0.048$
5	$E_5 = 0.068$	$E_5 = 0.037$	$E_5 = 0.052$
6	$E_6 = 0.065$	$E_6 = 0.052$	$E_6 = 0.050$
7	$E_7 = 0.064$	$E_7 = 0.056$	$E_7 = 0.048$

Table 3: The Ultimate Strength of the Specimen

SAMPLE	ULTIMATE STRENGTH (MPa)		
	HDPE	PET	LDPE
1	16.37	13.74	16.57
2	16.98	14.35	15.56
3	16.78	14.75	14.96
4	16.78	14.15	16.37
5	17.38	10.91	15.97
6	16.37	13.95	14.96
7	16.98	14.96	14.15

From the tensile tests, the percentage elongation for the three plastic materials were computed using Equation 4 defined as

$$E = \frac{L_f - L_i}{L_i} \times 100\%$$ (**Error! No text of specified style in document.**)

Where L_f is the final length of the material and L_i, the initial length.With an initial length of 37 mm for all specimen, the percentage elongation of the three materials were determined and tabulated and presented in Table 4.

Table 4: Percentage Elongation

ELONGATION (%)						
	HDPE		PET		LDPE	
SAMPLE	Final Length (mm)	Elongation (%)	Final Length (mm)	Elongation (%)	Final Length (mm)	Elongation (%)
1	142.24	284.43	134.62	263.84	91.44	147.14
2	177.80	380.54	114.30	208.92	58.42	57.89
3	175.26	373.68	124.46	236.38	38.10	2.97
4	165.10	346.22	157.48	325.62	48.26	30.43
5	134.62	263.84	99.06	167.73	50.80	37.30
6	154.94	318.76	137.16	270.70	40.65	9.86
7	144.78	291.30	106.68	188.32	38.56	4.22

NOTE: The initial length is 37 mm

The strength properties obtained from the tensile test of the materials under study differ from one sample to the other. A range was therefore used to represent the strength properties for each material. The ranges for the strength properties were determined using Equation 5.

$$\boldsymbol{E = E_{av} \pm \frac{t_{\alpha,v} s}{\sqrt{n-1}}} \qquad (5)$$

where E is the strength properties; E_{av}, the mean, s, standard deviation, $t_{\alpha,v,}$ t-distribution probability, n, the sample size (7) and v is n-1. But the mean and standard deviation were determined using Equations 6 and 7 respectively.

$$E_{av} = \frac{\sum E_i}{n} \qquad (6)$$

$$s = \sqrt{\frac{\sum (E_i - E_{av})2}{n}} \qquad (7)$$

where E_i is the strength property of the specimen.

Using a 95% confidence level, the value of $t_{0.05,6}$ was 1.94 from the *t*-distribution table. Hence, the strength properties for the three (3) plastic materials were computed and the results are represented in Table 5.

Table 5 Strength Properties of the Used Materials

SPECIMEN	MODULUS OF ELASTICITY (GPa)	ULTIMATE STRENGTH (MPa)	ELONGATION (%)
PET	0.0663± 0.010	16.80 ± 0.26	322.68 ± 33.37
HDPE	0.049 ± 0.004	13.83 ± 0.99	220.69 ± 45.56
LDPE	0.051 ± 0.003	15.51 ± 0.64	41.40 ± 37.20

These results were then compared with the strength properties of the virgin material to ascertain their possible engineering application.

3.2 Engineering Application of the Materials

From literature, the strength properties of the virgin materials are tabulated and presented in Table 6. These values were compared with the used plastic materials, as shown in Table 5.

From Tables 5 and 6, the percentage elongation of the used PET and HDPE falls within the range compared with the virgin material, whilst the used LDPE falls outside the range. However, the Young's moduli and the ultimate strengths of the used differ from that of the virgin materials. This implies that, the used plastic materials have lost some of their strength properties. Although, some properties must have been lost, they can still be used in engineering application. Hence, the percentage ration of the used and the virgin have been computed to determine their usage in engineering field.

Table 6: Strength Properties of the Virgin Materials

Specimen	Young's Modulus (GPa)	Ultimate Strength (MPa)	Percentage Elongation (%)
PET	>0.8	26-33	20-1000
HDPE	0.11-0.45	22-50	90-500
LDPE	0.11-0.45	25-50	90-500

Considering the ultimate strength, the percentage ratio for HDPE, PET and LDPE are 68.27%, 65.62% and 64.58% respectively. Also, the corresponding moduli of elasticity of the materials as a percentage of the virgin materials were obtained as 48.20% for HDPE, 8.45% for PET and 49.10% for LDPE. In spite of the decrease in mechanical properties, the recycled plastics are still useful as engineering materials.

4. CONCLUSIONS

The study showed the usefulness of high density polyethylene (HDPE), polyethylene terephthalate (PET) and low density polyethylene (LDPE) as engineering materials. There was an appreciable decrease in the ultimate tensile strength and modulus of elasticity of all the three plastics used in this study. The reason for the decrease in the mechanical properties of these recycled plastics may be due to the effect of temperature as a result of the extrusion process. Heat and cooling degrades thermoplastics. Also, contamination level and environmental conditions to which recycled plastics were exposed to could be possible reasons for the reduction in the mechanical properties of the plastics.

It can be concluded that

1. The materials are still useful since there is not much variation in mechanical properties of the virgin material and that of the recycled plastics.
2. The HDPE gives a higher percentage of mechanical properties compared with the other two materials.
3. The HDPE would be a very appropriate material to be used as a composite matrix for the possible construction of engineering products; for axample, a wind turbine blade.

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