

## Quantification of Losses in Properties of Recycled Plastics: A Comparative Study



### Engineering

**KEYWORDS :** Virgin Plastics, Wastes, Recycled Plastics, Property loss

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### ABSTRACT

*The application of additives, modifiers in the production of plastics, and usage makes properties of virgin plastics vary with that of recycled plastics. Mechanical properties of the plastics such as flexural strength, flexural modulus, tensile strength, tensile modulus, elongation impact strength and specific gravity were tested in this study. From the results, Tensile strength of High Density Polyethylene (HDPE) reduced by 19.4%, while that of Polyethylene Terephthalate (PET) reduced by 7.8%. The elongation of HDPE reduced by 17.8% while that of PET was 3.5%. The Young modulus of HDPE reduced by 36% while that of PET was 28%. The Specific gravity of HDPE increased by 5.3% while that of PET was 2.4%. The flexural strength of HDPE reduced by 13.2% while that of PET was 9.6%. The Impact strength of HDPE reduced by 20.2% while that of PET was 23.2%. The flexural modulus of HDPE reduced by 30.8% while that of PET was 31%. Statistical analysis on properties lost due to aging and recycling process was done using ANOVA.*

### 1 Introduction

Plastic materials have become part of our day to day life. It is found in all spheres of life and cannot be done without. Plastics are more widely used domestically and in the industry. Due to its non-biodegradable nature, the disposal of plastic waste has become cumbersome; it cannot be composted, occupies much space in landfills and creates greenhouse gasses when incinerated. Recycling of plastic wastes therefore, becomes the most effective way of dealing with this problem. Recycling prevents the throwing away of potentially useful materials, reduce the consumption of fresh raw materials, reduce energy usage, reduce air pollution (from incineration) and groundwater pollution (from land filling), reduces the need for "conventional" waste disposal, and lower greenhouse gas emissions compared to virgin production (Brydson, 1995). In the economic aspect, recycling makes a nation or individual to recover money otherwise lost through pollution, burning and burying of waste material. These recycled plastics are sources for various uses including engineering materials for construction and highway applications. Plastic waste recycling will complement the international concern for environment, and the government's campaign against deforestation and Ozone Layer depletion which leads to climate change. It will reduce environmental pollution caused by sachet water pack littering the street and bus-stop, and blocking the drainage.

Due to the application of various additives and modifiers in the production of plastic products, the properties of virgin plastics vary with that of recycled ones. Determining the properties of recycled plastics and comparing them with the properties of their virgin counterparts enables us to know the amount of the properties lost to aging and recycling process which in turn gives guidelines on the various applications in which recycled plastics can be put to use.

While recycled plastics have properties which are good enough for many applications, there has been little effort made to carefully characterize the specific mechanical properties of recycled plastics. Therefore, the objective of the study was to determine the mechanical properties of virgin and recycled plastics compare the properties of virgin plastics to that of recycled plastics and evaluate the amount of properties lost as a result of aging and recycling, which in turn influences their suitability for a particular purpose.

### 2.0 Literature Review

Recycling of plastics have generated controversial debate. Studies and research have argued that recycling offers more benefits which include conservation of oil, **reduction of greenhouse gas emissions**, saving of landfill space and conservation of energy ( Korhonen & Dahlbo, 2007, Stuart R. and David E., 2003,

Harold C.R. 2003). As plastics are widely used in industry, more plastic wastes needs to be recycled for both economic and environmental reasons. There is an almost limitless range of products that can be produced from plastic (McCrum, 1988).

On the other hand, critics of recycling often claim that more resources are wasted in recycling than is saved. Proponents of recycling dispute each of these claims, and the validity of arguments from both sides has led to enduring controversy. Kord, B. et. al (2011) studied the effect of virgin and recycled plastics on moisture sorption of Nanocomposites from newsprint fiber and organoclay . Chang-Sik H. et. al (1996) carried out a comparative studies to investigate the effectiveness of several compatibilizers for three kinds of virgin plastic mixtures in order to gain insight into the recycling of wastes from those frequently encountered mixed plastics. Kiaeifar et. al (2011) studied a comparative investigation on the mechanical properties of wood plastic composites made of virgin and recycled plastics. Mahendrasinh et. al (2013) studied the mechanical properties of recycled polypropylene blended with virgin polypropylene.

### 3.0 Materials and Methodology

This study deals only with virgin PET and HDPE plastics obtained from Science Equipment Developing Institute (SEDI) at Alkwoke, Enugu State and waste plastic materials collected at the different waste disposal units. The recycled materials were collected, sorted, and processed at Scientific and Equipment Development Institute (SEDI). The Injection molding production process was used for both the virgin and recycled materials. The recycled PET was obtained from drinking water bottles. The recycled materials for HDPE were gotten from jerry cans and milk bottles. Each of the different test was carried out using a simple Completely Randomized Design (CRD) experiment, replicated 5 times with 2 treatment levels for Virgin and Recycled HDPE and PET. All the plastic properties were tested under room temperature.

#### 3.1 Tensile Testing

Extensometer was used to carry out this test. The tensile tests generate a stress strain diagram. 3kg of injection molded PET was placed between the grips of the inspiron of the extensometer. The machine pulls the sample until failure just before it broke. The ultimate tensile strength and elongation were measured and recorded. The tensile modulus was calculated from the readings obtained from the machine. The procedure was repeated for a 3kg HDPE plastic. The properties obtained from this experiment are as follows:

#### 3.2 Ultimate Tensile Strength (UTS)

The ultimate tensile strength is the force per unit area (MPa) required to break a plastic. The ability to resist breaking under

tensile stress is one of the most important and widely measured properties of materials used in structural applications. The ultimate tensile strength was calculated thus:

$$\sigma = \frac{\text{Force}}{\text{Area}} \tag{1}$$

Where Force was measured by the machine and the area was the original cross sectional area.

**3.3 Elongation**

The ultimate elongation of a plastic is the percentage increase in length that occurs before it breaks under tension. The combination of high ultimate tensile strength and high elongation leads to plastics of high toughness.

$$\text{Elongation (\%)} = (L_f - L_i / L_i) * 100 \tag{2}$$

Where  $L_f$  is the length at break, and  $L_i$  is the initial length of the specimen.

**3.4 Tensile Modulus of Elasticity (E)**

The tensile modulus is the ratio of stress to elastic strain in tension. A high tensile modulus means that the material is rigid- more stress is required to produce a given amount of strain.

$$E = \Delta\sigma / \Delta\varepsilon \tag{3}$$

Where  $\sigma$  is stress and  $\varepsilon$  is the strain exerted on the sample.

**3.5 Izod Impact strength**

Instron 5565 model was used to carry this test. The sample (HDPE & PET, virgin and recycled) which was 3.5mm thick and notched, was fixed at its position. The pendulum swung on its track and struck the sample. The energy lost (required to break the sample) as the pendulum continued on its path was measured from the distance covered and recorded.

**3.6 Specific gravity**

This experiment was started by first weighing the empty pycnometer. The pycnometer was filled with Isopropyl alcohol and placed in a water bath until temperature equilibrium with the bath was attained. The weight of the pycnometer filled with Isopropyl alcohol was determined. After cleaning and drying the pycnometer, 1-5 g of recycled plastics material was added and weight of the specimen plus the pycnometer was determined. The pycnometer was then filled with Isopropyl alcohol in a vacuum desiccator. The vacuum was applied until all the air had been removed from between the particles of the specimen. Last, the weight of the pycnometer filled with Isopropyl alcohol and the specimen was recorded. The specific gravity is calculated as follows:

$$\text{Specific gravity} = \frac{a}{(b + a - m)} \tag{4}$$

Where a= weight of the specimen; b= weight of the pycnometer filled with Isopropyl alcohol; m = weight of the pycnometer containing the specimen and filled with Isopropyl alcohol.

**3.7 Flexural Tests**

For flexural strength and flexural modulus determination, the samples were specified (dimensioned) according to International Standard Organization (ISO) i.e. 10mm x 4mm x 80mm. It was determined using Universal Tester and Flexural Test Fixtures.

The sample was measured to determine the length, width and thickness. The loading speed was set according to standard (2mm/min). The sample was placed on the support and the force applied at midspan. The force and deflection was measured and recorded.

The strength was calculated thus,

$$\sigma_f = \frac{3FL}{2bh^2} \tag{5}$$

Where  $\sigma_f$  is the flexural strength; F is the applied force; L is the length; b is the width; and h is the thickness. The strain was calculated thus,

$$\varepsilon_f = \frac{6sh}{L^2} \tag{6}$$

Where  $\varepsilon_f$  is the flexural strain; s is the deflection; h is the thickness; and L is the length of the sample.

The flexural modulus was calculated thus,

$$E_f = \Delta\sigma_f / \Delta\varepsilon_f \tag{7}$$

Where  $E_f$  is the flexural modulus;  $\Delta\sigma_f$  is change in flexural stress;  $\Delta\varepsilon_f$  is change in flexural strain.

**4.0 Results and Discussion**

The result of the Ultimate Tensile Strength, Elongation, Young Modulus, Specific Gravity, Izod Impact strength, Flexural strength and Flexural modulus tests carried out on the samples are as shown in Table 1.

**Table 1: Summary of Results of Ultimate Tensile Strength, Elongation, Young Modulus, Specific Gravity, Izod Impact strength, Flexural strength and Flexural modulus tests.**

Average Value	Virgin HDPE	Recycled HDPE	% Change	Virgin PET	Recycled PET	% Change
Ultimate Tensile Strength	15.281	12.322	19.340	58.680	54.111	7.786
Elongation	5.229	4.298	17.800	1.256	1.072	3.519
Young Modulus	1.427	0.832	36.060	3.639	2.619	28.030
Specific Gravity	0.957	1.008	5.330	1.362	1.395	2.420
Izod Impact strength	19.17	15.11	20.18	1.64	1.26	23.17
Flexural strength	40.058	34.785	13.160	80.824	72.589	9.630
Flexural modulus	0.721	0.499	30.790	1.240	0.856	30.970

**5. Discussion of Results**

From the above table, it is seen that most of the mechanical properties decreased in the recycled materials with the exception of the specific gravity. The tensile strength of HDPE decreased by 19.3% while PET decreased by 7.8%. The elongation of HDPE decreased by 17.8% while that of PET was 3.5%. The Young Modulus of HDPE decreased by 36% while that of PET was 28%. The Specific gravity of HDPE increased by 5.3% while that of PET was 2.4%. The flexural strength of HDPE decreased by 13% while that of PET has a decrease of 9.6%. The Impact strength of HDPE decreased by of 20.2% while that of PET was 23.2%. The Flexural modulus of HDPE decreased by 30.8% while that of PET has a decrease of 31%. Generally and from all indications, PET is a stronger plastic than HDPE.

Evaluation of the amount of properties lost as a result of aging and recycling process was done using ANOVA Microsoft Excel worksheet. The null hypothesis which stands to be approved or rejected, states that there is no effect of aging or recycling on the recycled samples. The statistical analysis shows that aging and recycling process has a great effect on the UTS of HDPE; elongation, Young Modulus, specific gravity, Izod impact, flexural strength, and Flexural modulus of HDPE and PET. However it has minimal effect on the UTS of PET. Details of the statistical analysis are given below

The ANOVA analysis shows that there is significant difference in the UTS of virgin and recycled HDPE (since  $F = 61.475 > F_{crit} = 5.3177$ ). But there is no significant difference in the UTS of PET ( $F = 1.2701 < F_{crit} = 5.3177$ ). Also, there is significant difference in the elongation property of virgin and recycled HDPE (since  $F = 5.4384 > F_{crit} = 5.3177$ ) and PET ( $F = 23.403 > F_{crit} = 5.3177$ ). There is significant difference in Young Modulus of virgin and recycled HDPE (since  $F = 23.403 > F_{crit} = 5.3177$ )

and PET ( $F = 5.8278 > F_{crit} = 5.3177$ ). There is significant difference in the specific gravity of virgin and recycled HDPE ( $F = 43.626 > F_{crit} = 5.3177$ ) and PET ( $F = 41.861 > F_{crit} = 5.3177$ ). There is significant difference in the impact strength of virgin and recycled HDPE ( $F = 1200.8 > F_{crit} = 5.3177$ ) and PET ( $F = 19.613 > F_{crit} = 5.3177$ ). There is significant difference in the flexural strength of virgin and recycled HDPE ( $F = 11.711 > F_{crit} = 5.3177$ ) and PET ( $F = 748.3 > F_{crit} = 5.3177$ ). There is significant difference in the flexural Modulus of virgin and recycled HDPE ( $F = 319.8966 > F_{crit} = 5.3177$ ) and PET ( $F = 27.85846 > F_{crit} = 5.3177$ ).

The recycled plastics did not lose much of their properties and can be processed into secondary products for which they are suitable. The properties can further be strengthened by rein-

forcements and additives such as impact modifiers, anti-static agents, antioxidants, carbon, glass, mica, etc.

## 5. CONCLUSION

The study compared the properties of virgin plastics to that of recycled plastics and evaluated the amount of properties lost as a result of aging and recycling. The statistical analysis shows that aging and recycling process has a significant effect on the Ultimate testing stress (UTS) of HDPE. However, it has a minimal effect on the UTS of PET. With the above analysis, PET has lesser ability to break under tension, lesser rate of deformation, more rigid, tougher, and stiffer than HDPE. Its superior qualities are evident in its applications for packaging food materials while HDPE plastics are suitable for numerous applications in Industries.

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