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PHYSICO-MECHANICAL PROPERTIES OF VIRGIN POLYSTYRENE (PS) AND WASTE HIGH DENSITY POLYETHYLENE (HDPE) BLEND

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ABSTRACT

Today's technology requires materials with amalgamated properties which are deficient in the usual class of polymers, making polymer blending an alternative in the field of material science and engineering. However, the large quantity of plastic waste generated daily, issues associated with waste management in Nigeria and low decay rate of high density polyethylene (HDPE) is hazardous to the environment and health. For these reasons, studies on the mechanical and physical properties of high density polyethylene (HDPE) and Polystyrene (PS) blended at different proportions was investigated in this work. The waste high density polyethylene, pure polystyrene and blended samples were characterized for tensile strength, hardness, density, water absorption and modulus of elasticity. The results of the tests indicated that sample F (50 % HDPE/50 % PS) out of all modified polymer blend has the highest tensile strength, Young's modulus and density of 34.62 MPa, 752.61 MPa and 1.02 g/cm^3 respectively. While, sample D (70 % HDPE/30 % PS) has the highest percentage elongation, moisture content and hardness of 5.1 7 %, 0.267 % and 97.6 Shores respectively among other blends. Thus, this shows that sample F has the highest density and the stiffest compared to other blends, and on the other hand sample D has the best water absorption capacity of 0.267 %, most ductile and the hardest among other blends. Also, based on the results obtained, the ultimate tensile strength, modulus of elasticity and density of the samples increases gradually while, the percentage elongation decreases gradually as the percentage of polystyrene increases progressively and, this was because sample G (0

%HDPE/100 %PS) has higher tensile strength (41.77 MPa), modulus of elasticity (2776.40 MPa) and density (1.062 g/cm^3) but lower percentage elongation (1.505 %) compared to sample A (100 %HDPE/0 %PS) with tensile strength, modulus of elasticity, density and percentage elongation of 30.93 MPa, 606.07 MPa, 0.959 g/cm^3 and 5.105 % respectively.

KEYWORDS: Polystyrene (PS), High Density Polyethylene (HDPE), Polymer blends, Waste plastic recycling, Plastic waste management, Density test, Modulus of elasticity, Water absorption, Tensile strength, Percentage elongation, Hardness, Mechanical testing, Material characterization, Sustainable materials engineering.

1.0 INTRODUCTION

In modern times, technology requires polymeric materials with hybrid properties that cannot be met by conventional polymers such as polyvinyl chloride (PVC), polyteraphthelate (PET), polyethylene (PE), polystyrene (PS), etc. As a result, technologist, engineers and scientist are bound to explore unconventional polymeric materials to meet the numerous necessities for today's applications. Among the preferred material properties essentials are low density, strong abrasion, impact resistant and corrosion resistant. These material property combination and ranges have been met and are yet been broadened by the improvement of blend materials (Brydson, 2016).

Polymers are simply large molecules or macromolecules composed of many repeated subunits, while polymer blends on other hand are physical mixture of two or more polymers and are commercially prepared by mechanical mixing which is achieve through screw compounders and extruders (Momoh *et al*., 2006).

The blending of polymers provides an efficient way of developing new materials with tailored properties, which is often a faster and more cost-effective means of achieving a desired set of properties than synthesizing a new polymer (Chirawithayaboon and Kiatkamjornwong, 2004).

However, despite the fact that the polymers (PS and PE) are widely used individually, there are few literatures on PS and PE blends, some of which are; compatibilization of PE/PS and PE/PP blends: Effect of processing conditions and formulation (Tasnim *et al*., 2002). Here, the characteristics of compatibilized and uncompatibilized blends were found to be the same.

Also, morphology and properties of SEBS (poly [styrene-b-(ethylene-co-butylene)-b-styrene]) block copolymer compatibilized PS/HDPE blends (Versna *et al*., 2007). Here, twin-screw extruders were used and morphology was obtained by means of SEM and TEM. Another literature is; properties of recycled PS/SBR blends: Effect of SBR pretreatment (Justine and Denis, 2015). Here, twin-screw extrusion followed by injection moulding were used to produce samples. For this reason, in this research work, the polymers (PS/waste HDPE) are to be blended at different compositions using roll mill instead of extruders to obtain a polymer of distinct properties from the two, having balanced properties without using compatibilizers since the characteristics of compatibilized and uncompatibilized PE/PS blends have been found to be the same (Tasnim *et al*., 2002).

As a matter of fact, the large quantity of plastic waste generated daily and its management in Nigeria has been an issue for decades. Also, the low decay rate of plastics like; high density polyethylene (HDPE) is hazardous to the environment and health. Thus, blending it with polystyrene would serve as a means of recycling it and making the environment safer.

More so, high density polyethylene (HDPE) has higher water absorption capacity and elongation (i.e. better ductility) but lower density, tensile modulus and tensile strength when compared to polystyrene (PS). However, this variation in properties have not been fully explored in creating a new material of balanced properties through polymer blending. Hence, this research work would help to explore this idea.

The aim of this work is to evaluate the physico-mechanical properties of polystyrene/waste high density polyethylene blend. This was achieved through the following objectives:

- To investigate the effect of proportioning on the properties of waste high density polyethylene and polystyrene blend.
- To characterize the blend for properties such as density, percentage moisture content, percentage elongation, hardness, modulus of elasticity and tensile strength.

The justifications for the aim and objectives of this research work include:

1. Recycling waste high density polyethylene thus, a means of waste management.
2. Developing a new material of balanced properties different from that of the individual properties of high density polyethylene and polystyrene, suitable for certain science and engineering applications.

3. To provide data on the properties of polystyrene/waste high density polyethylene blend which are rarely available currently.

The scope of this work is limited to characterising physico-mechanical properties of polystyrene (PS) and waste high density polyethylene (HPDE) blended at different proportions. Using a two-roll mill, station compression machine and mould of size.

2.0 INSTRUMENTATION AND METHODOLOGY

2.1 Instrumentation

2.1.1 Materials

Table 2.1: List of Materials.

S/N	MATERIALS	AVAILABILITY
1	High density polyethylene (HDPE) waste	A.B.U. Environs
2	Polystyrene	Polymer workshop, NILEST
3	Processing oil	Polymer workshop, NILEST
4	Moulds	Polymer workshop, NILEST
5	Stopwatch	Polymer workshop, NILEST
6	Hack saw	Polymer workshop, NILEST
7	Scrapper	Polymer workshop, NILEST

2.1.2 Equipment

Table 2.2: List of Equipment

S/N	EQUIPMENT	MANUFACTURER	MODEL NUMBER	AVAILABILITY
1	Two roll mill	Reliable rubber and plastic machinery company	5185	Polymer workshop, NILEST
2	Compression machine	Carver Inc., Wabash, U.S. A	3851	Polymer workshop, NILEST
3	Hardness tester	Muver durometer	5019	Physical Testing Lab., NILEST
4	Weighing balance	A and D instrument	ANDHR-200-BC	Polymer Lab., NILEST
5	Impact tester	CEAST Resil Family	6957	Polymer Lab., NILEST
6	Tensiometer	Houndfield tensiometer	W6465 5019	Mech. Engr., A.B.U.

2.2 METHODOLOGY

The step-by-step methodology used in describing the details of developing the blend and the experimental procedures that was followed for the characterization and evaluation of the samples in Table 2.3 is described as follows.

Table 2.3: Proportions of Various Sample.

S/N	SAMPLES	PROPORTIONS (%)
1.	A	100 HDPE/0 PS
2.	B	90 HDPE/10 PS
3.	C	80 HDPE/20 PS
4.	D	70 HDPE/30 PS
5.	E	60 HDPE/40 PS
6.	F	50 HDPE/50 PS
7.	G	0 HDPE/100 PS

2.2.1 Weighing and Compounding

Firstly, 100 g of waste HDPE (100 %HDPE/0 %PS) was measured using a weighing balance and kept separately and the same was repeated for 100 g PS (0 %HDPE/100 %PS), both serving as control samples. Then, five other samples with proportions in percentage of mass of waste HDPE/PS blend were prepared, i.e. sample B (90 %HDPE/10 %PS), sample C (80 %HDPE/20 %PS), sample D (70 %HDPE/30 %PS), sample E (60 %HDPE/40 %PS), and sample F (50 %HDPE/50 %PS). Thus, making a total of seven samples. Afterwards, the two-roll mill machine was allowed to heat up to a temperature of 150 ^{o}C for both the rear and front roll and used for compounding of each sample.

2.2.2 Heat Pressing

The temperature of the heavy-duty compression machine was set at 150 ^{o}C with a pressure of 2.5 MPa. Processing oil was applied on the mould and each sample to be pressed was placed in the mould, covered and put into the machine. The samples were preheated for about 5 minutes, compressed for about 10 minutes and cooled for about 5 minutes using the heavy-duty compression machine. Hacksaw was used to cut each sample into desired shape (dumbbell) and sizes required to carry out the tensile strength test. Mould of size was used to give each sample the required shape for carrying out other tests.

2.2.3 Density Test

Density was calculated from the mass obtained with the weighing balance and the calculated volume from the dimensions of each sample.

2.2.4 Hardness Test

A Durometer (shore A type) was used, where the readings for each sample were taken five times and the results obtained are recorded.

2.2.5 Tensile Strength Test

Each sample was cut into dumbbell shape using the hack saw and a tensiometer was used to plot the graph of load against extension for each sample from which the results of the load at break and extension were obtained and recorded. Other properties like percentage elongation, ultimate tensile strength and modulus of elasticity were calculated from the results of extension and load at break obtained for each sample.

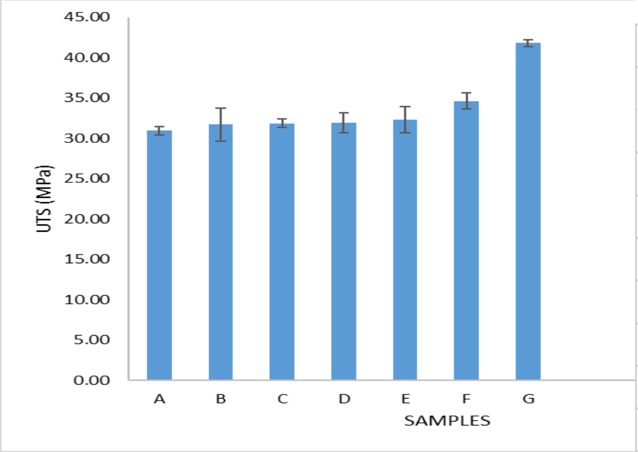
2.2.6 Water Absorption Test

Each sample was immersed in water for 24 hours to allow water to be absorbed and, afterwards their individual moisture content in percentage were calculated and recorded.

3.0 RESULTS AND DISCUSSION

3.1 Effect of Polymer Blend on Tensile Strength

The effect of blend proportioning on the ultimate tensile strength (UTS) of each sample is illustrated in Figure 3.1 which is plotted from the data in Figure A1, A2, A3 and Table A3 of the appendix. The result shows the progressive change from sample A, B, C, D, E, F to G, (i.e. 30.93 MPa, 31.69 MPa, 31.85 MPa, 31.92 MPa, 32.27 MPa, 34.62 MPa to 41.77 MPa respectively), however, these incremental change was due to different proportioning of polymers (waste HDPE and PS) blended which affect the mechanical properties (Ebewele, 2000). More so, sample G had the highest tensile strength (41.77 MPa) and sample A had the least (30.93 Mpa), which is in range with those in literature, since it justifies that the tensile strength of pure PS (35-55 MPa) is higher than pure HDPE (30.5-33 MPa) (Shackelford *et al*, 2015). However, sample F out of all modified polymer blend has the highest tensile strength of 34.62 MPa among the blends.



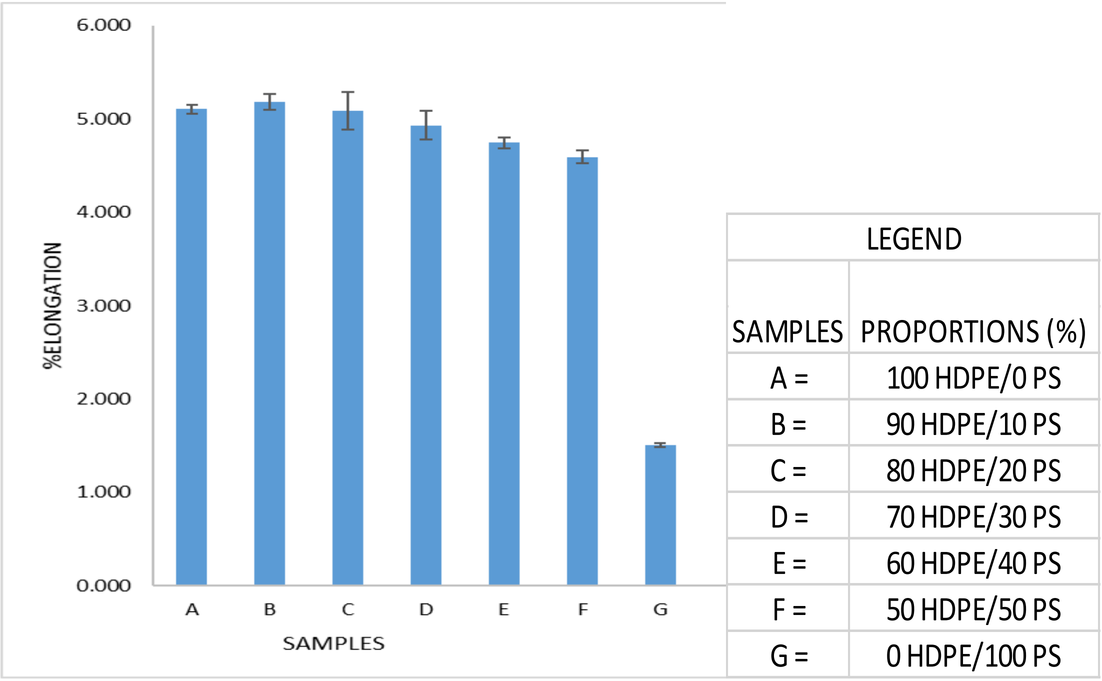
LEGEND	
SAMPLES	PROPORTIONS (%)
A =	100 HDPE/0 PS
B =	90 HDPE/10 PS
C =	80 HDPE/20 PS
D =	70 HDPE/30 PS
E =	60 HDPE/40 PS
F =	50 HDPE/50 PS
G =	0 HDPE/100 PS

Figure 3. 1: Effect of blend on the ultimate tensile strength of each sample.

3.2 Effect of Polymer Blend on Elongation

Figure 3.2 illustrates the effect of blending the polymers at varying compositions with respect to elongation which is plotted from the data in Figure A1, A2, A3 and Table A5 of the appendix. It shows that sample B of about 5.17 % elongation is the most ductile material among other samples. The elongation of sample A (5.11 %) was slightly below those in literature (7-12 %) may be as a result of degradation of waste HDPE due to subjection under certain temperature condition which tends to affect the mechanical properties (Harper, 2002).

Also, Figure 3.2 indicates increase in elongation from sample A to B (i.e. 5.11 % to 5.17 %) and decrease from sample B, C, D, E, F to G, (i.e. from 5.17 %, 5.09 %, 4.94 %, 4.74 %, 4.60 to 1.51 % respectively). This gradual decrease might be as a result of gradual increase in the proportion of polystyrene (with elongation of about 1.34-3.54 %) which has lower elongation compared to HDPE (with elongation of about 7-12 %) in literature (Brydson, 1999).



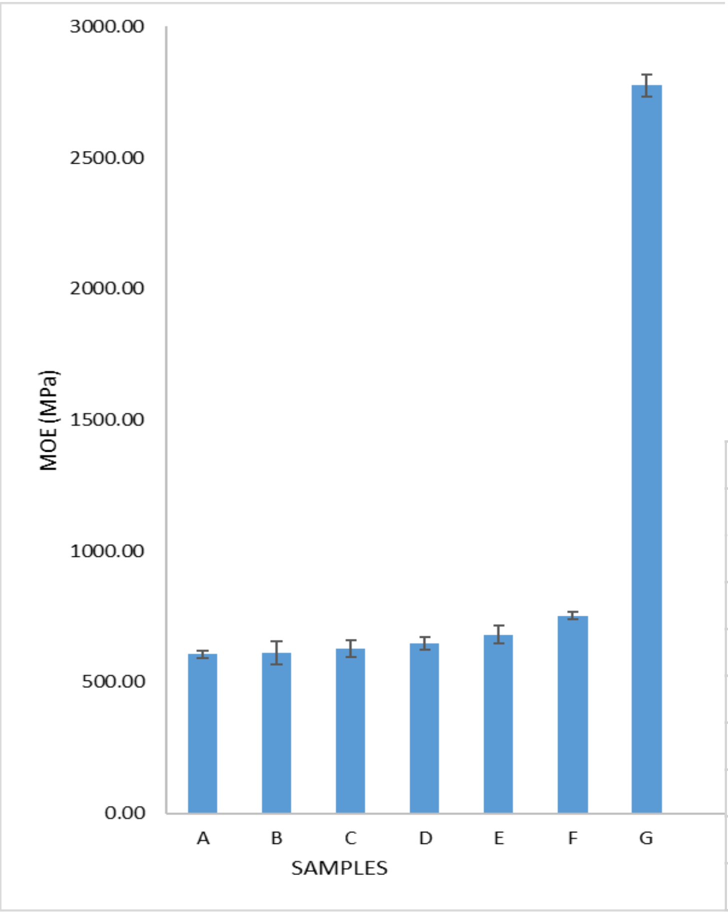
SAMPLES	PROPORTIONS (%)
A =	100 HDPE/0 PS
B =	90 HDPE/10 PS
C =	80 HDPE/20 PS
D =	70 HDPE/30 PS
E =	60 HDPE/40 PS
F =	50 HDPE/50 PS
G =	0 HDPE/100 PS

Figure 3.2: Effect of blend on the percentage elongation of each sample.

3.3 Effect of Polymer Blend on Modulus of Elasticity (Moe)

The results in Figure 3.3 indicates the effect on each sample of various proportion with respect to modulus of elasticity (MOE) plotted from data in Figure A1, A2, A3 and Table A3 of the appendix. These results demonstrate how MOE varies in each sample due to difference in their composition, where sample G had the highest MOE of 2758.4 MPa and sample A had the least value of 604.78 MPa.

However, sample F has the second highest modulus of elasticity of 752.61 MPa making it the blend with the highest MOE since, modulus of elasticity (MOE) is a function of strength and stiffness thus, it is of paramount significance for most polymer application (Ebewele, 2000).



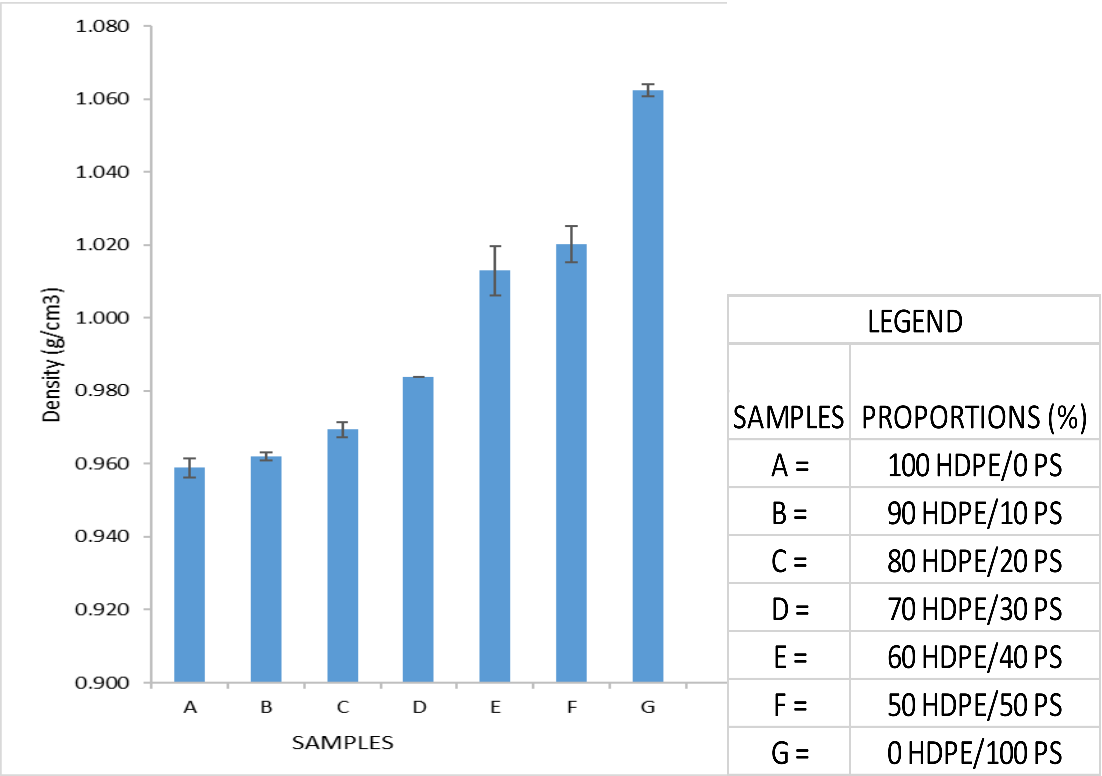
LEGEND	
SAMPLES	PROPORTIONS (%)
A =	100 HDPE/0 PS
B =	90 HDPE/10 PS
C =	80 HDPE/20 PS
D =	70 HDPE/30 PS
E =	60 HDPE/40 PS
F =	50 HDPE/50 PS
G =	0 HDPE/100 PS

Figure 3.3: Effect of blend on the MOE of each sample.

3.4 Effect of Polymer Blend on Density

Figure 3.4 depicts the effect on each sample of various proportion as regard to their respective densities plotted from data in Table A7 of the appendix. These results demonstrate how density increases in each sample due to the increasing composition of polystyrene, where sample G had the highest density of 1.062 g/cm^3 and sample A has the least density of 0.959 g/cm^3. More so, sample F has the second highest density of 1020.11 kg/m^3 thus, the highest density among other blends. This gradual increase might be as a result of gradual increase in the proportion of polystyrene (with density of about 1.05-1.10

g/cm^3) which is higher compared to HDPE (with density of about 0.93-0.96 g/cm^3) in literature (Shackelford *et al*, 2015).



LEGEND	
SAMPLES	PROPORTIONS (%)
A =	100 HDPE/0 PS
B =	90 HDPE/10 PS
C =	80 HDPE/20 PS
D =	70 HDPE/30 PS
E =	60 HDPE/40 PS
F =	50 HDPE/50 PS
G =	0 HDPE/100 PS

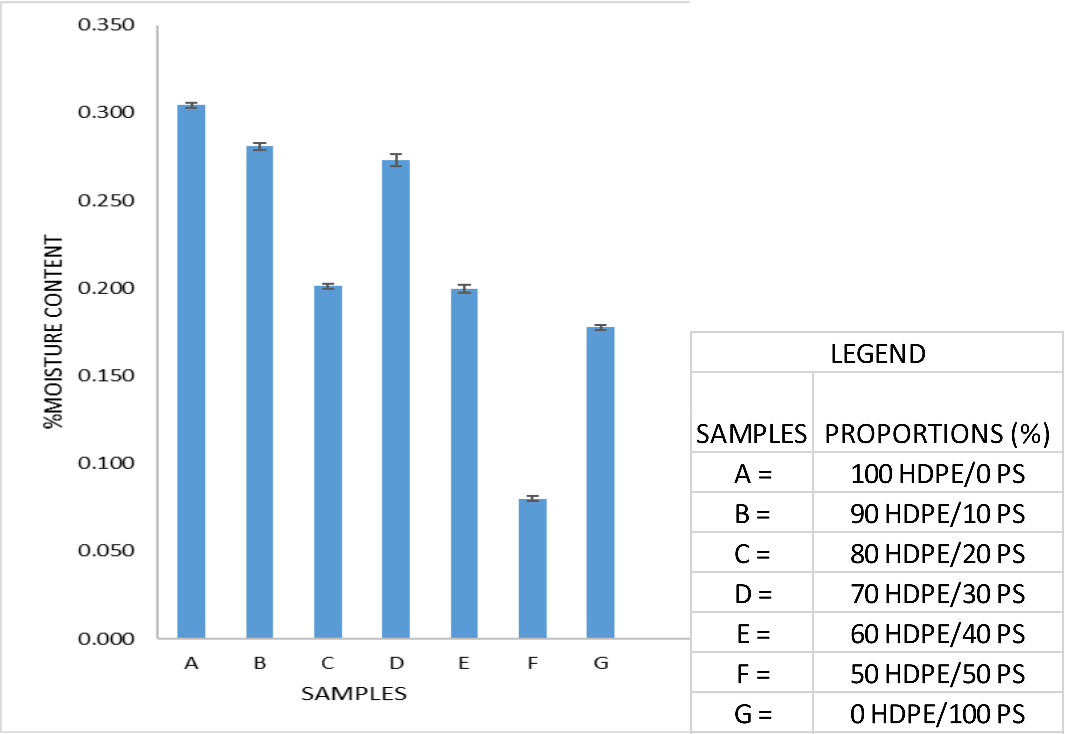
Figure 3.4: Effect of blend on the density of each sample.

3.5 Effect of Polymer Blend on Water Absorption

Figure 3.5 illustrates the effect of blending at varying compositions in relationship to their individual water absorption capacity (moisture content) after soaking each of them in water for a period of 24 hours where the data from Table A9 in the appendix was plotted. It showed that sample A had the highest moisture content (i.e. water absorption capacity) of 0.303 % and sample F has the least of about 0.097 %. The elongation of sample A was slightly below those in literature (i.e. 0.5-1.2 % for HDPE), which may be as a result of degradation of waste HDPE due to subjection under certain temperature condition which tends to affect the mechanical properties (Harper, 2002).

Furthermore, Figure 3.5 indicates decreasing moisture content from sample A, B, to C (i.e. from 0.303 %, 0.279 % to 0.204 %) then, a sharp increase in sample D (i.e. 0.267 %), thereafter a decrease from sample D, E to F (i.e. from 0.267 %, 0.197 % to 0.079 % respectively). More so, sample G which is pure polystyrene had a moisture content of 0.179 %.

However, these variations might be as a result of different blending proportions of polystyrene and waste HDPE. Therefore, from the water absorption chart, sample B is the polymer blend with highest water absorption capacity among other blends.



SAMPLES	PROPORTIONS (%)
A =	100 HDPE/0 PS
B =	90 HDPE/10 PS
C =	80 HDPE/20 PS
D =	70 HDPE/30 PS
E =	60 HDPE/40 PS
F =	50 HDPE/50 PS
G =	0 HDPE/100 PS

Figure 3.5: Effect of blend on the moisture content of each sample.

3.6 EFFECT OF POLYMER BLEND ON HARDNESS

The effect of blend proportioning on the hardness of each sample is illustrated in Figure 3.6 which is plotted from the data in Table A10 of the appendix. The result shows that sample A and B had the same hardness value of about 96.2 Shores then, a retrogressive change from sample B to C (i.e. from 96.2 Shores to 95.8 Shores), however, this decrease was as a result of different proportioning of polymers (waste HDPE and PS) blended (Ebewele, 2000).

In addition, sample D has the highest value of 97.6 Shores making it the hardest among the samples, thereafter a decrease from sample D, E to F (i.e. from 97.6 Shores, 96.4 Shores to 93.7 Shores). Also, sample G which is pure polystyrene has about 94.8 shores of hardness. These variations might be as a result of variation in the proportion of polystyrene (of about 93-95 Shores) which is lower compared to HDPE (of about 96-98 Shores) in literature (Shackelford *et al*, 2015).

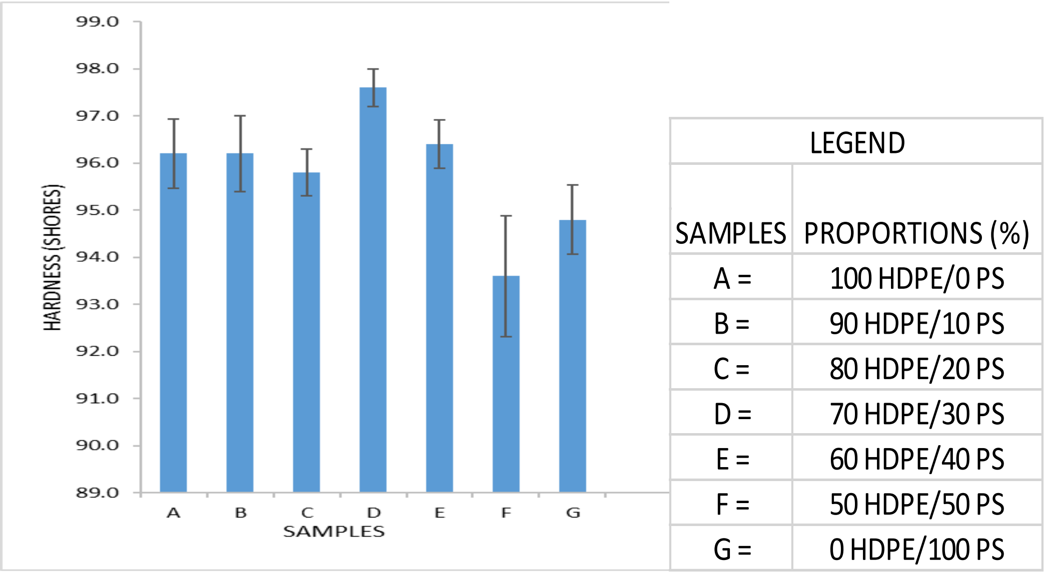


Figure 3.6: Effect of blend on the hardness of each sample.

Table A.1: Width and thickness readings from the tensiometer for each sample.

Tensile strength test							
Guage length, gl = 35 mm							
Sample	**Proportions (%)**	**Width, w (mm)**			**Thickness,t (mm)**		
		W_1	**W_2**	**W_3**	**T_1**	**T_2**	**T_3**
A	100 HDPE/0 PS	5.7	5.7	5.6	2.9	2.9	3.0
B	90 HDPE/10 PS	7.2	7.0	7.1	3.0	2.8	2.9
C	80 HDPE/20 PS	8.2	8.2	8.1	3.0	3.0	2.9
D	70 HDPE/30 PS	7.5	7.6	7.5	2.9	2.9	2.8
E	60 HDPE/40 PS	8.1	8.1	8.2	2.9	3.0	3.0
F	50 HDPE/50 PS	8.0	7.9	7.9	2.8	2.8	2.9
G	0 HDPE/100 PS	7.9	7.8	7.8	2.7	2.7	2.8

Table A.2: Load results and the calculated area for each sample.

Tensile strength test							
Guage length, gl = 35 mm							
Sample	**Proportions (%)**	**Load, l (n)**			**Area, a (mm^2)**		
		L_1	**L_2**	**L_3**	**A_1**	**A_2**	**A_3**
A	100 HDPE/0 PS	526	498	518	16.53	16.53	16.80
B	90 HDPE/10 PS	676	694	584	21.60	19.60	20.59
C	80 HDPE/20 PS	762	784	768	24.60	24.60	23.49
D	70 HDPE/30 PS	668	676	722	21.75	22.04	21.00
E	60 HDPE/40 PS	824	784	725	23.49	24.30	24.60
F	50 HDPE/50 PS	772	807	754	22.40	22.12	22.91
G	0 HDPE/100 PS	873	883	927	21.33	21.06	21.84

Calculating the area of each sample:

For sample A;

In a similar manner, the areas the other six samples (i.e. B, C, D, E, F, and G) are calculated and tabulated as seen in Table A2 above and, the load results were taken and tabulated in the same Table A2 above from the graph of load verses extension plotted by the tensiometer for each samples.

Table A.3: Calculated ultimate tensile strength for each sample.

Tensile strength test							
Guage length, gl = 35 mm							
Samples	**Proportions (%)**	**Utimate tensile strength σ, (mpa)**					
						S.D.	**S.E.**
A	100 HDPE/0 PS	31.82	30.13	30.83	30.93	0.8508	0.49123
B	90 HDPE/10 PS	31.30	35.41	28.36	31.69	3.5388	2.04315
C	80 HDPE/20 PS	30.98	31.87	32.69	31.85	0.8598	0.49641
D	70 HDPE/30 PS	30.71	30.67	34.38	31.92	2.1299	1.22968
E	60 HDPE/40 PS	35.08	32.26	29.47	32.27	2.8036	1.61867
F	50 HDPE/50 PS	34.46	36.48	32.91	34.62	1.7908	1.0339
G	0 HDPE/100 PS	40.93	41.93	42.45	41.77	0.7711	0.44518

Calculating the ultimate tensile strength (σ) of each sample:

For sample A;

Average ultimate tensile strength of sample A,

Standard Deviation (S.D.) =
= = 0.8508 MPa

Standard Error (S.E.) = = = 0.49123 MPa

In a similar manner, the average ultimate tensile strength, standard deviation and standard error of each of the other samples (i.e. B, C, D, E, F, and G) are calculated and tabulated as seen in Table A3 above.

Table A.4: Extension Results for each sample.

Tensile strength test				
Guage length, gl = 35 mm				
Samples	**Proportions (%)**	**Extension, Δl (mm)**		
		ΔL1	ΔL2	ΔL3
A	100 HDPE/0 PS	1.78	1.82	1.76
B	90 HDPE/10 PS	1.76	1.82	1.86
C	80 HDPE/20 PS	1.92	1.70	1.72
D	70 HDPE/30 PS	1.62	1.78	1.78
E	60 HDPE/40 PS	1.68	1.62	1.68
F	50 HDPE/50 PS	1.62	1.64	1.56
G	0 HDPE/100 PS	0.52	0.54	0.52

Table A.5: Calculated elongation for each sample.

Tensile strength test				
Guage length, gl = 35 mm				
Samples	**Proportions (%)**	**Elongation, ε**		
		ε_1	**ε_2**	**ε_3**
A	100 HDPE/0 PS	0.050857	0.052000	0.050286
B	90 HDPE/10 PS	0.050286	0.052057	0.053143
C	80 HDPE/20 PS	0.054857	0.048571	0.049143
D	70 HDPE/30 PS	0.046286	0.050857	0.050857
E	60 HDPE/40 PS	0.048000	0.046286	0.048000
F	50 HDPE/50 PS	0.046286	0.046857	0.044571
G	0 HDPE/100 PS	0.014857	0.015429	0.014857

Calculating the elongation of each sample:

For sample A;

Elongation, ε =

= 0.050857

= 0.052000

= 0.050286

In a similar manner, the elongation of each of the other samples (i.e. B, C, D, E, F, and G) are calculated and tabulated as seen in Table A5 above.

Table A.6: Calculated percentage elongation of each sample.

Tensile strength test							
Guage length, gl = 35 mm							
Samples	**Proportions (%)**	**Percentage elongation, %ε**					
		$\%\varepsilon_1$	**$\%\varepsilon_2$**	**$\%\varepsilon_3$**	**%**	**S.d.**	**S.e.**
A	100 hdpe/0 ps	5.0857	5.2000	5.0286	5.105	0.087	0.050
B	90 hdpe/10 ps	5.0286	5.2057	5.3143	5.183	0.144	0.083
C	80 hdpe/20 ps	5.4857	4.8571	4.9143	5.086	0.348	0.201
D	70 hdpe/30 ps	4.6286	5.0857	5.0857	4.933	0.264	0.152
E	60 hdpe/40 ps	4.8000	4.6286	4.8000	4.743	0.099	0.057
F	50 hdpe/50 ps	4.6286	4.6857	4.4571	4.590	0.119	0.069
G	0 hdpe/100 ps	1.4857	1.5429	1.4857	1.505	0.033	0.019

Percentage elongation, %ε =

= = 5.0875

= = 5.2000

= = 5.0286

Average percentage elongation for sample A, %

Standard Deviation (S.D.) = %

= = 0.087 %

Standard Error (S.E.) = = = 0.050 %

In a similar manner, the average percentage elongation, standard deviation and standard error of each of the other samples (i.e. B, C, D, E, F, and G) are calculated and tabulated as seen in Table A6 above.

Table A.7: Calculated modulus of elasticity for each sample.

Tensile strength test							
Guage length, gl = 35 mm							
Samples	**Proportions (%)**	**Modulus of elasticity, e (mpa)**					
		E_1	**E_2**	**E_3**		**S.d.**	**S.e.**
A	100 HDPE/0 PS	625.69	579.37	613.16	606.07	23.963	13.835
B	90 HDPE/10 PS	622.37	680.18	533.72	612.09	73.770	42.591
C	80 HDPE/20 PS	564.66	656.15	665.30	628.70	55.651	32.130
D	70 HDPE/30 PS	663.54	603.09	676.03	647.56	39.010	22.522
E	60 HDPE/40 PS	730.81	697.05	613.99	680.62	60.117	34.709
F	50 HDPE/50 PS	744.60	778.60	738.40	753.86	21.642	12.495
G	0 HDPE/100 PS	2754.79	2717.54	2856.88	2776.40	72.139	41.649

Calculating the modulus of elasticity of each sample:

For sample A;

Modulus of elasticity (E) =

= = = 625.69 MPa

= = = 579.37 MPa

= = = 613.16 MPa

Average modulus of elasticity for sample A,

Standard Deviation (S.D.) =

= = 23.963 MPa

Standard Error (S.E.) = = = 13.835 MPa

In a similar manner, the average modulus of elasticity, standard deviation and standard error of each of the other samples (i.e. B, C, D, E, F, and G) are calculated and tabulated as seen in Table A7 above.

Table A.8: Mass readings of each sample using the digital weighing balance.

Density test					
Samples	**Proportions (%)**	**Mass readings, m (g)**			**Volume, v (cm^3)**
		m_1	**m_2**	**m_3**	
A	100 HDPE/0 PS	28.71	28.92	28.67	30.00
B	90 HDPE/10 PS	28.82	28.93	28.83	30.00
C	80 HDPE/20 PS	29.11	28.96	29.17	30.00
D	70 HDPE/30 PS	29.51	29.51	29.52	30.00
E	60 HDPE/40 PS	30.19	30.18	30.79	30.00
F	50 HDPE/50 PS	30.48	30.43	30.9	30.00
G	0 HDPE/100 PS	31.83	31.82	31.97	30.00

Calculating the volume of each sample

For sample A;

Volume, V = Length, l Breadth, b Thickness, t = 10 cm 10 cm 0.3 cm = 30 cm^3

In a similar manner, the volumes of each of the other sample (i.e. B, C, D, E, F, and G) are calculated and tabulated as seen in Table A8 above since, all samples have the same dimensions.

Table A.9: Calculated densities of each sample.

Density Test							
Samples	**Proportions (%)**	**Density, (g/cm^3)**					
						S.D.	**S.E.**
A	100 HDPE/0 PS	0.957	0.964	0.956	0.959	0.0045	0.0026
B	90 HDPE/10 PS	0.961	0.964	0.961	0.962	0.0020	0.0012
C	80 HDPE/20 PS	0.970	0.965	0.972	0.969	0.0036	0.0021
D	70 HDPE/30 PS	0.984	0.984	0.984	0.984	0.0002	0.0001
E	60 HDPE/40 PS	1.006	1.006	1.026	1.013	0.0116	0.0067
F	50 HDPE/50 PS	1.016	1.014	1.030	1.020	0.0086	0.0050
G	0 HDPE/100 PS	1.061	1.061	1.066	1.062	0.0028	0.0016

Calculating the density of each sample

Here, the mass readings of each sample were taken three times and, the density of each was evaluated and arranged in tabular form.

For sample A;

First reading, = 28.71 g

= 0.957 g/

Second reading, = 28.92 g

= 0.964 g/

Third reading, = 28.67g

= 0.956 g/

Average density of sample A,

Standard Deviation (S.D.) =

= = 0.0045 g/cm^3

Standard Error (S.E.) = = = 0.0026 g/cm^3

In a similar manner, the average density, standard deviation and standard error of each of the other samples (i.e. B, C, D, E, F, and G) are calculated and tabulated as seen in Table A9 above.

Table A.10: Mass readings of each sample before and after soaking in water.

Water absorption test							
		Mass readings, m (g)					
		Before soaking			**After soaking (24hrs)**		
Samples	**Proportions (%)**						
A	100 HDPE/0 PS	2.3434	2.3433	2.3435	2.3505	2.3505	2.3506
B	90 HDPE/10 PS	1.7215	1.7214	1.7216	1.7263	1.7263	1.7264
C	80 HDPE/20 PS	2.2030	2.2029	2.2031	2.2074	2.2073	2.2076
D	70 HDPE/30 PS	1.6850	1.6851	1.6850	1.6896	1.6896	1.6897
E	60 HDPE/40 PS	2.8388	2.8387	2.8388	2.8444	2.8443	2.8446
F	50 HDPE/50 PS	2.7901	2.7901	2.7902	2.7923	2.7923	2.7925
G	0 HDPE/100 PS	2.2335	2.2334	2.2334	2.2375	2.2373	2.2374

Table A.11: Calculated percentage moisture content of each sample.

Water absorption test							
		Moisture content, (g)			**%moisture content, %**		
Sample	**Proportions (%)**				**%**	**%**	**%**
A	100 HDPE/0 PS	0.0071	0.0072	0.0071	0.303	0.307	0.303
B	90 HDPE/10 PS	0.0048	0.0049	0.0048	0.279	0.285	0.279
C	80 HDPE/20 PS	0.0044	0.0044	0.0045	0.200	0.200	0.204
D	70 HDPE/30 PS	0.0046	0.0045	0.0047	0.273	0.267	0.279
E	60 HDPE/40 PS	0.0056	0.0056	0.0058	0.197	0.197	0.204
F	50 HDPE/50 PS	0.0022	0.0022	0.0023	0.079	0.079	0.082
G	0 HDPE/100 PS	0.0040	0.0039	0.004	0.179	0.175	0.179

Calculating the moisture content and percentage moisture content of each sample:

For sample A;

Moisture content () = Mass after soaking () – Mass before soaking ()

= 2.3505 g – 2.3434 g = 0.0071 g

= 2.3505 g – 2.3433 g = 0.0072 g

= 2.3506 g – 2.3435 g = 0.0071 g

Percentage moisture content

In a similar manner, the moisture content and percentage moisture content of each of the other samples (i.e. B, C, D, E, F, and G) are calculated and tabulated as seen in Table A11 above.

Table A.12: Calculated average percentage moisture content of each sample.

Water absorption test				
Sample	**Proportions (%)**		**S.D.**	**S.E.**
A	100 HDPE/0 PS	0.304	0.00248	0.00143
B	90 HDPE/10 PS	0.281	0.00337	0.00194
C	80 HDPE/20 PS	0.201	0.00261	0.00151
D	70 HDPE/30 PS	0.273	0.00594	0.00343
E	60 HDPE/40 PS	0.200	0.00407	0.00235
F	50 HDPE/50 PS	0.080	0.00207	0.00119
G	0 HDPE/100 PS	0.178	0.00258	0.00149

Calculating the average percentage moisture content of each sample:

Average percentage moisture content of sample A,

Standard Deviation (S.D.) =

= = 0.00248 %

Standard Error (S.E.) = = = 0.00143 %

In a similar manner, the average percentage moisture content, standard deviation and standard error of each of the other samples (i.e. B, C, D, E, F, and G) are calculated and tabulated as seen in Table A12 above.

Table A.13: Hardness readings for each sample using the shore (A) hardness tester.

Durometer shore (a) hardness test									
		Meter readings, h (shores)							
Samples	**Proportions (%)**	H_1	H_2	H_3	H_4	H_5		**S.D.**	**S.E.**
A	100 HDPE/0 PS	97	94	98	97	95	96.2	1.64	0.735
B	90 HDPE/10 PS	95	95	97	99	95	96.2	1.79	0.800
C	80 HDPE/20 PS	97	96	94	96	96	95.8	1.10	0.490
D	70 HDPE/30 PS	97	98	99	97	97	97.6	0.89	0.400
E	60 HDPE/40 PS	96	95	97	96	98	96.4	1.14	0.510
F	50 HDPE/50 PS	97	90	92	93	96	93.6	2.88	1.288
G	0 HDPE/100 PS	96	95	96	95	92	94.8	1.64	0.735

Calculating the average hardness of each sample:

For sample A;

Average hardness = 96.2 Shores

Standard Deviation (S.D.) =

=

= 1.64 Shores

Standard Error (S.E.) = = = 0.735 Shores

In a similar manner, the average hardness, standard deviation and standard error of each of the other samples (i.e. B, C, D, E, F, and G) are calculated and tabulated as seen in Table A13 above.

4.0 CONCLUSION AND RECOMMENDATION

4.1 Conclusion

Based on the results obtained, the ultimate tensile strength, modulus of elasticity and density of the samples increases gradually while, the percentage elongation decreases gradually as the percentage of polystyrene increases progressively. This was because sample G (0 %HDPE/100 %PS) has higher tensile strength (41.77 MPa), modulus of elasticity (2776.40 MPa) and density (1.062 g/cm^3) but lower percentage elongation (1.505 %) compared to sample A (100 %HDPE/0 %PS) with tensile strength, modulus of elasticity, density and percentage elongation of 30.93 MPa, 606.07 MPa, 0.959 g/cm^3 and 5.105 % respectively.

Furthermore, it can be inferred that, sample with 50 % HDPE/50 % PS out of all modified polymer blend had the highest tensile strength, Young's modulus and density of about 34.62 MPa and 752.61 MPa and 1.02 g/cm^3 respectively thus, it is the stiffest and densest among the blends. Also, sample D (70 %HDPE/30 %PS) of about 5.17 % elongation, 0.267 % moisture content and a hardness of 97.6 Shores, shows the highest elongation and moisture content out all modified blends hence, it is the most ductile material, has the best water absorption capacity and the hardest among other blends.

4.2 RECOMMENDATION

The recommendations from the conclusion and for the entire research work includes stabilizers should be added to reduce degradation of various polymer blends also, properties other than physico-mechanical ones like; thermal, electrical and microscopic should be investigated to add to the data base of waste HDPE/PS blends.

In addition, other form of polyethylene apart from HDPE like; LLDPE and LDPE should be blended with PS for investigation and comparison of properties with those of waste HDPE/PS blends.

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