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PRODUCTION PROCESSING FOR THE BENEFICIATION OF WASTE POLYTHYLENE PRODUCT

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ABSTRACT

The large amount of post-consumer polyethylene terephthalate (PET) bottles/containers and post-consumer sachet water nylon currently generated in Lagos State makes imperative the search for alternative procedures for treating, recycling or reuse of these waste materials. This is because they are not biodegradable and constitute environmental and health threat to the survival of man and other living things. The sustainable approach to municipal solid waste management in Nigeria is being considered. This research work aimed at recycling of post-consumer PET bottles/containers and post-consumer sachet water nylon to produce composite materials for engineering applications and wastes storage bag (wastes bin) respectively. Plastic waste, polyethylene terephthalate (PET) bottles/containers and sachet water nylon coming from the dumpsites in Lagos State in Nigeria were collected, separated, washed, recycled, extruded and characterized. The products obtained were subjected to tests to evaluate their mechanical properties using Introns Tester Model 1122. The results showed that the PET/LDPE blend mechanical properties depend on the processing conditions and apparatus. High processing temperature and high residence times strongly enhance the degradation processes and reduce the mechanical properties, in particular the elongation at break. However, by introducing additives, such as antioxidants, inert fillers and impact modifiers, these mechanical properties are improved and approached those products made from of virgin polyethylene terephthalate. For the recycled sachet water nylon, the results also showed that there was mechanical properties deficiency in the use of recycled resins and that this deficiency could be minimized through adequate blending with virgin resins. In general, provided that optimal reprocessing conditions with suitable additives, the mechanical properties of the recycled resins are near to those of virgin resins.

Contribution/Originality: This study could be able to address the burden of disposed some of these plastic bottle /nylon litter and block the drainages. Also help in area of employment because many idle hands can engage in picking the waste for recycle.

1. INTRODUCTION

Polymeric materials allow the manufacture of a wide variety of low-cost, high-performance products, and contribute to continuous energy saving and sustainable development [1]. The inert nature and biodegradation resistance of synthetic polymers have created, however, an important environmental dilemma concerning their waste management [2, 3]. The optimization of waste management procedures should imply a multidisciplinary approach based on a hierarchy, in which prevention, waste minimization, waste reuse, waste recovery and, lastly, disposal should be prioritized, in that order [4]. Options for plastic waste recovery, in contraposition to landfill disposal, include material recycling and energy recovery procedures [5, 6].

As a whole, recycling processes (mechanical and feedstock recycling) involve material recovery from plastic waste streams, whereas combustion procedures for heat production with controlled emissions are included in energy recovery options. Mechanical recycling entails the production through physical means of new plastic products from plastic waste. In feedstock recycling, plastic wastes are cracked and depolymerized by chemical means into a series of petrochemical products or monomers, which can be later transformed into new polymeric products by synthesis [7-9]. Finally, energy recovery employs polymeric waste streams as fuel for energy production, exploiting the high calorific content of plastics [10, 11].

Plastic wastes should receive renewed consideration as valuable resources for product manufacturing, with a similar status to virgin oil-based plastics and polymers of biological origin [12]. The origin of the plastic waste streams—that is, the end-of-life application sector— determines the management challenges and the technological procedures to be implemented for the successful recycling of their plastic waste [13]. A valuable classification has been proposed for the plastic waste streams according to their origin, based on the following sources: packaging, agriculture, municipal solid waste (MSW), construction and demolition (C&D), end-of-life vehicles (ELV), and waste electrical and electronic equipment (WEEE) [14].

General bottlenecks that restrict the effective implementation of recycling activities include technological, management, and commercial issues [15]. There are inherent difficulties in the management, dismantling, identification, and separation of mixed plastic waste streams, together with limited scientific knowledge about the influence of recycling processes on the composition, structure, and properties of polymeric materials [16]. In addition, plastic wastes may contain contaminants and hazardous substances; consequently, environmental concerns and policy issues hinder their reuse [17, 18]. The introduction of standardized procedures for the quick and reliable characterization of recycled materials would unquestionably help in the quality assessment of recycled products [19].

2. METHODOLOGY

2.1. Mechanical Recycling

Mechanical recycling, also known as secondary recycling, is the process of recovering plastic solid waste (PSW) for the re-use In manufacturing plastic products via mechanical means [20]. It was promoted and commercialized all over the world back in the 1970s. Mechanical recycling of PSW can only be performed on single-polymer plastic, e.g. PE, PP, PS, PET etc [21]. The more complex and contaminated the waste, the more difficult it is to recycle it mechanically [22]. Separation, washing and preparation of PSW are all essential to produce high quality, clear, clean and homogenous end-products. One of the main issues that face mechanical recyclers is the degradation and heterogeneity of PSW. Since chemical reactions that constitute polymer formation (i.e. polymer-addition, polymerization and poly-condensation) are all reversible in theory, energy or heat supply can cause photo-oxidation and/or mechanical stresses which occur as a consequence [23]. Length or branching of polymer chains can also occur from the formation of oxidized compounds and/or harsh natural weathering conditions [20, 24, 25]. Due to the previously stated reasons, it is very important to have a customer ready to purchase the product to achieve a

sensible economic and environmental practice. Nevertheless, mechanical recycling opens an economic and viable route for PSW recovery, especially for the case of foams and rigid plastics [26].

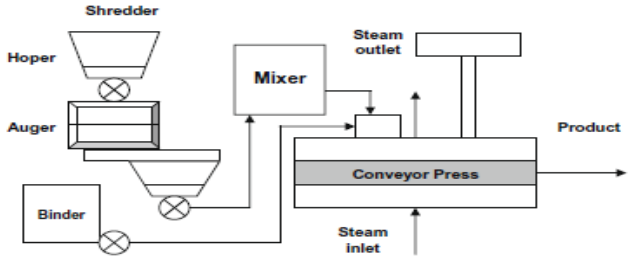

Fig-1. Schematic of Flexible Foam Re-bonding, adapted from Zia, et al. [26]

2.2. Thermolysis Schemes and Technologies

2.2.1. Pyrolysis (Thermal Cracking of Polymers in Inert Atmospheres)

Thermolysis is the treatment of PSW in the presence of heat under controlled temperatures without catalysts. Thermolysis processes can be divided into advanced thermo-chemical or pyrolysis (thermal cracking in an inert atmosphere), gasification(in the sub-stoichiometric presence of air usually leading to CO and CO_2 production) and hydrogenation (hydrocracking) [27]. Fig. 2.2shows different thermolysis schemes, current main techologies and their main obtained products.

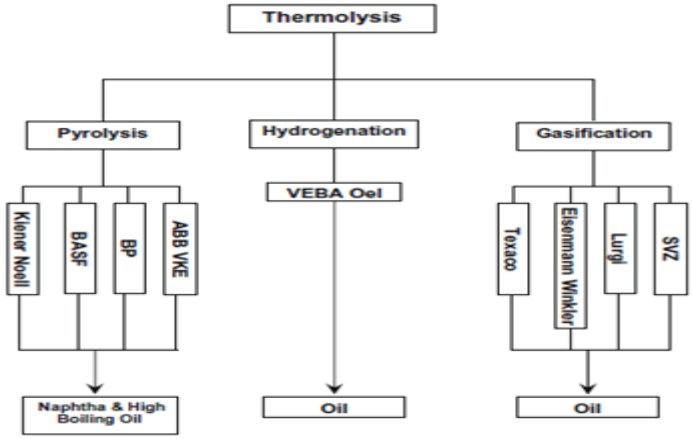

Fig-2. Different Thermolysis Schemes with Reverence to the main Technology.
Source: Mastellone [20]

3. MATERIALS

Post-consumer polyethylene terephthalate (PET) bottles/containers, post-consumer sachet water nylon, water, virgin LDPE, virgin HDPE, master match, additives (anti-oxidant, inert filler, modifier agent)

The apparatus thus consist the following

(i) Washing machine
(ii) Crushing/grinding machine,
(iii) Milling machine, dryer
(iv) Shredder,
(v) Pelletizing machine,
(vi) Closed mixer,
(vii) Single screw extruder, and twin-screw extruder,
(viii) Beam balance,

Istron Tester Model 1122.

3.1. Experimental Analysis

3.1.1. Post–Consumer PET Bottles/Containers Conversion

The experiment was carried out in three different apparatus namely; Closed Mixer, Single-Screw Extruder, Twin-Screw Extruder at the Recycling Unit, Arkem Nigeria Ltd and Lagos Waste Management Authority (LAWMA. Single-screw extruder (D = 25mm, L/D = 19) and twin-screw compounder (D = 42mm, L/D = 7) equipped with a ribbon-type head were used. Both extruders were attached to Brabender Plasticoder PLE 651 with thermal profile 140 – 170 – 185 – 210°C and 140 – 180 – 210°C respectively, with a rotational speed of 100rvm. The detailed procedures are presented as follow:

i. **Washing:** Postconsumer PET bottles/containers collected were washed with mild detergent and warm water to remove impurities and food particles.
ii. **Separation:** The cover, labels and glue on the bottles were then removed and dried.
iii. **Crushing/Grinding:** The dried cleaned post-consumer PET bottles/containers were then fed into the crusher where they are crushed and grinded into smaller pieces or flakes.
iv. **Milling:** Separate, single-polymer plastics are milled together.
v. **Agglutination:** The products were gathered and collected either to be stored and sold later on after the addition of pigments and additives, or sent for further processing.
vi. **Extrusion:** The plastic flakes were extruded to strands and then pelletized to produce pellets of single-polymer plastic.
vii. **Quenching:** This involved water-cooling the plastic by water to be granulated and sold as a final product.

Extrusion Moulding: The resins or PSW pellets were then moltened and extruded through a mould by single-screw extruder and twin-screws compounder to form a moulded product. from this process was fibre.

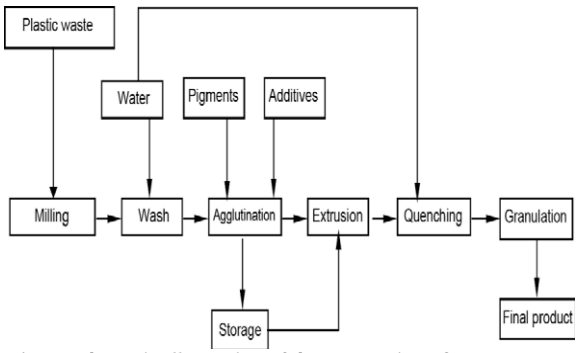

Fig-3. Schematic Illustration of the Conversion of Post-consumer PET Bottles/Containers to Useful Pro
Source: Aznar, et al. [11]

3.1.2. Post-Consumer PET Sachet Water Nylons Conversion

The study was carried out at the Olusosun Landfills Recycling Centre, Ikeja, Nigeria of the Lagos Waste Management Authority (LAWMA) is presented as follow:

i. **Washing:** Post-consumer sachet water nylon collected were properly washed with warm water to remove sand and other particles and then dried under the sun.
ii. **Crushing/Grinding:** Dried cleaned post-consumer sachet water nylon was then fed into the crusher where they are crushed and grinded into smaller pieces.
iii. **Shredding:** The pieces of nylon were then fed into the shredder where they are converted into shredded pieces or chips.
iv. **Washing and Drying:** The chips were later sent to an electric washing machine and thereafter dried in an electric dryer.

v. **Recycling/Extrusion:** Dried shredded nylons are then fed into the recycling machine which has rotating screw in a barrel surrounded by heating element that causes plastication to form strands.

vi. **Pelletizing:** Strands produced from the extrusion die and allowed to pass through a water basin by a mechanical system into pelletizer which chopped the strands into short uniform cylindrical pellets.

vii. **Extrusion Moulding:** Virgin LDPE & master batch, and pellets (recycled materials) are mixed together and fed into the twin-screws extruder (D = 42mm, L/D = 7) where they are converted into final product black nylon. This was then cut into different sizes including waste-storage bins.

This experiment was performed for 100% virgin resins, 100% recycled resins, 50/50% virgin/recycled, 40/60% virgin/recycled resins and 30/70% virgin/recycled re

4. RESULTS AND DISCUSSION

The influence of temperature of the recycling apparatus, additives such as anti-oxidant, inert filler, modifier agent on the mechanical properties of reprocessed PET/virgin LDPE blend was evaluated in three different apparatus namely closed Mixer (M), Single-Screw Extruder (SS) and Twin-Screw Extruder (TS) at 180oC and 210oC are presented in tables 1 to 7. These results are also depicted by figures 4 to 13 using bar charts. The bar charts have been used because of the following reasons amongst others: Bar charts are easy to compute and understand. They show the trends in the mechanical properties of the materials at glance. They allow for easier comparison between the results of the experiments

Table-1. Mechanical Properties of the Recycled PET/virgin LDPE Reprocessed in Different Apparatus at 180oC. As observed in table 1, the tensile strength of the product from recycled resins reprocessed in the mixer and single-screw extruder is almost the same while the twin-screw extruder is higher. The variation in the elastic modulus of products from different apparatus is quite small.

Apparatus/Mechanical Properties	Closed Mixer (M)	Single-Screw Extruder (SS)	Twin-Screw Extruder (TS)
Elastic Modulus, E (MN/m²)	299	305	291
Tensile Strength, TS (MN/m²)	10.2	10.5	11.1
Elongation at Break, EB (%)	82	195	217

Source: Is the results of experiment carried out

Table-2. Mechanical Properties of the Recycled PET/virgin LDPE Reprocessed in Different Apparatus at 210°C. In table .2, elastic modulus an elongation at break of the products from the different apparatus decrease in the order mixer (M) < single-screw extruder (SS) < twin-screw extruder (TS). However, the tensile strength remains almost the same in the different apparatus.

Apparatus/Mechanical Properties	Closed Mixer (M)	Single-Screw Extruder (SS)	Twin-Screw Extruder (TS)
Elastic Modulus, E (MN/m²)	292	288	279
Tensile Strength, TS (MN/m²)	10.2	10.2	10.3
Elongation at Break, EB (%)	87	228	240

Source: Is the results of experiment carried out

Table-3. Mechanical Properties of the Recycled PET/virgin LDPE Reprocessed in the presence of Anti-oxidant (Phosphite stabilizer) in Different Apparatus at 210°C. table.3 shows that the mechanical properties of recycled resins reprocessed in the different apparatus improved as result of the presence of anti-oxidant in the polymer matrix.

Apparatus/Mechanical Properties	Closed Mixer (M)	Single-Screw Extruder (SS)	Twin-Screw Extruder (TS)
Elastic Modulus, E (MN/m²)	298	315	295
Tensile Strength, TS (MN/m²)	11.2	11.4	10.1
Elongation at Break, EB (%)	170	325	342

Source: Is the results of experiment carried out

Table-4. Mechanical Properties of the Recycled PET/virgin LDPE Reprocessed in the Presence of Anti-oxidant (Phosphite stabilizer)and Inert Filler ($CaCO_3$ or Calcium Silicate)in a Twin-Screw Extruder at 210°C. Table 4.4 shows that the elastic modulus, the tensile strength and the elongation at break are being enhanced due to the presence of inert filler in the polymer matrix.

Mechanical Properties	PS + $CaCO_3$10%	PS + $CaCO_3$20%	PS + CaSiO10%	PS + CaSiO20%
Elastic Modulus, E (MN/m^2)	251	389	344	398
Tensile Strength, TS (MN/m^2)	12.1	11.9	11.6	13.1
Elongation at Break, EB (%)	375	405	382	308

Source: Is the results of experiment carried out

Table-5. Mechanical Properties of the Recycled PET/virgin LDPE Reprocessed in the Presence of Anti-oxidant (Phosphite stabilizer)and Modifier Agent (LDPE, EVA or Recycled PE) in a Twin-Screw Extruder at 210°C. Table 5 shows that the elastic modulus, the tensile strength and the elongation at break are being enhanced due to the presence of modifier agent in the polymer matrix. The EVA has the highest impact on the properties.

Mechanical Properties	PS + LDPE20%	PS + RPE20%	PS + EVA10%	PS + EVA20%
Elastic Modulus, E (MN/m^2)	269	258	245	236
Tensile Strength, TS (MN/m^2)	11.1	12.6	13.2	14.4
Elongation at Break, EB (%)	532	470	494	655

Source: Is the results of experiment carried out

Table-6. Comparison of Mechanical Properties of the Recycled PET/virgin LDPE to Virgin PET Reprocessed in the Twin-Screw Compounder at 210°C. Table 6 shows that with suitable incorporation of anti-oxidant, inert filler and modifier agent, we can achieve good properties of elastic modulus and elongation at break while the tensile strength remain smaller when compare to that of virgin PET.

Mechanical Properties	TS + Virgin PET	TS + PS + $CaCO_3$20%	TS + PS + EVA20%	TS + PS + $CaCO_3$20% + EVA10%
Elastic Modulus, E (MN/m^2)	297	389	236	419
Tensile Strength, TS (MN/m^2)	23.1	11.9	14.4	11.1
Elongation at Break, EB (%)	691	405	655	622

Source: Is the results of experiment carried out

Table-7. Variation of Mechanical Properties with Composition Changes for Virgin LDPE/Recycled Nylon. The table shows the gradual increase in percentage reduction in mechanical properties of product as the percentage of recycled nylon in the composition increase. This behaviour showed that the recycled resins has been thermo-mechanically degraded but can be upgraded by adding suitable amount of the virgin resins.

Mechanical Properties	100% Virgin Resins	50/50% Virgin/Recycled Resins	40/60% Virgin/Recycled Resins	30/70% Virgin/Recycled Resins	100% Recycled Resins
Ultimate Tensile Stress	22.50	12.50	7.70	4.95	2.50
Elongation	42.00	37.00	26.00	12.00	7.60
Yield Stress	32.40	25.00	21.84	13.50	9.50
Shear Strain	40.81	32.44	26.90	10.92	6.90
Shear Stress	22.39	17.72	13.32	8.51	4.20
Young Modulus	23.49	22.40	15.25	3.60	2.20

Source: Is the results of experiment carried out

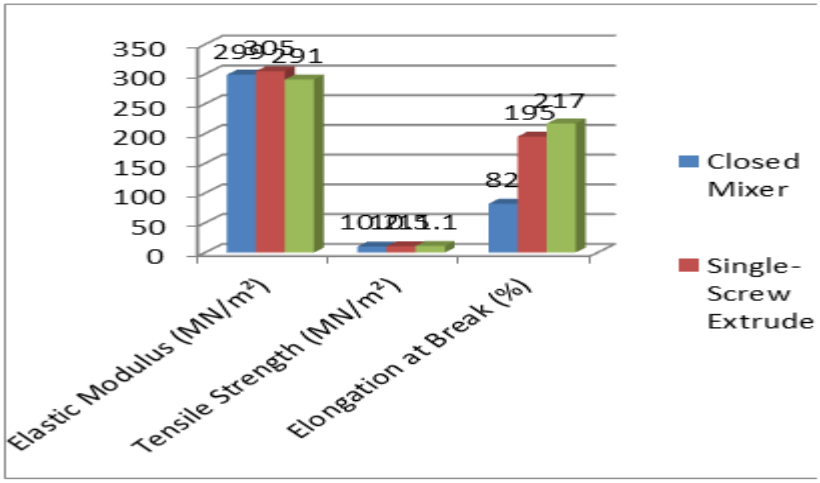

Fig-4. Mechanical Properties of the Recycled PET/virgin LDPE Reprocessed in Different Apparatus at 180°C
Source: Is the results of experiment carried out

As observed in Fig. 4 the tensile strength of the product from recycled resins reprocessed in the mixer and single-screw extruder is almost the same while the twin-screw extruder is higher. The variation in the elastic modulus of products from different apparatus is quite small. However, the elongation at break is highly influenced by the reprocessing apparatus.

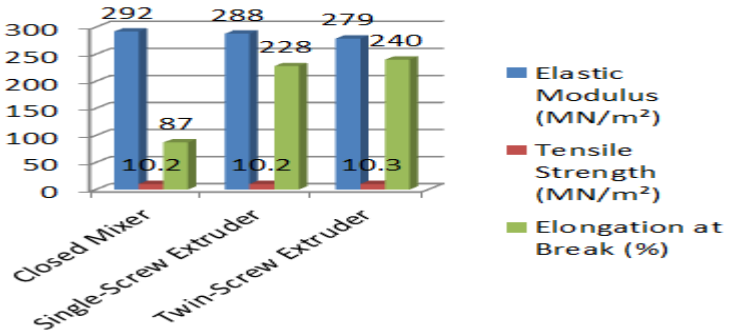

Fig-5. Mechanical Properties of the Recycled PET/virgin LDPE Reprocessed in Different Apparatus at 210°C
Source: Is the results of experiment carried out

In Fig. 5 above, elastic modulus and elongation at break of the products from the different apparatus decrease in the order mixer (M) < single-screw extruder (SS) < twin-screw extruder (TS). However, the tensile strength remains almost the same in the different apparatus.

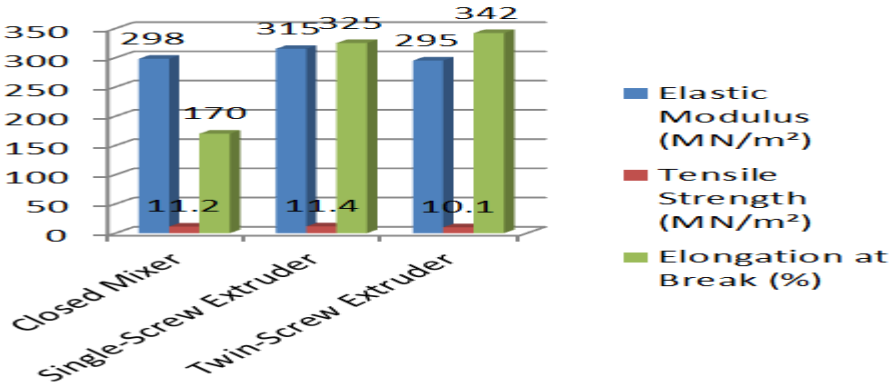

Fig-6. Mechanical Properties of the Recycled PET/virgin LDPE Reprocessed in the presence of Anti-oxidant (Phosphite stabilizer)in Different Apparatus at 210°C
Source: Is the results of experiment carried out

Fig. 6 shows that the mechanical properties of recycled resins reprocessed in the different apparatus improved as result of the presence of anti-oxidant in the polymer matrix.

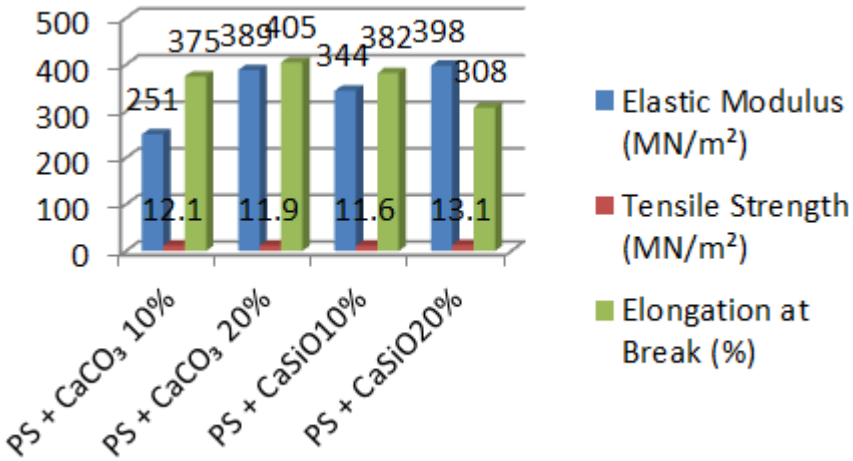

Fig-7. Properties of the Recycled PET/virgin LDPE Reprocessed in the Presence of Anti-oxidant (Phosphite stabilizer)and Inert Filler ($CaCO_3$ or CaSiO) in a Twin-Screw Extruder at 210°C

Source: Is the results of experiment carried out

Fig. 7 shows that the elastic modulus, the tensile strength and the elongation at break are being enhanced due to the presence of inert filler in the polymer matrix.

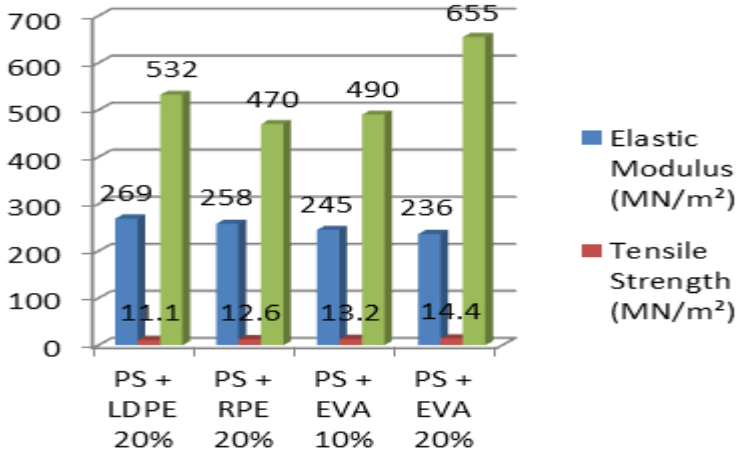

Fig-8. Mechanical Properties of the Recycled PET/virgin LDPE Reprocessed in the Presence ofAnti-oxidant (Phosphite stabilizer) and Modifier Agent (LDPE, EVA or Recycled PE) in aTwin-Screw Extruder at 210°C

Source: Is the results of experiment carried out

Fig. 8 shows that the elastic modulus, the tensile strength and the elongation at break are being enhanced due to the presence of modifier agent in the polymer matrix. The EVA has the highest impact on the properties.

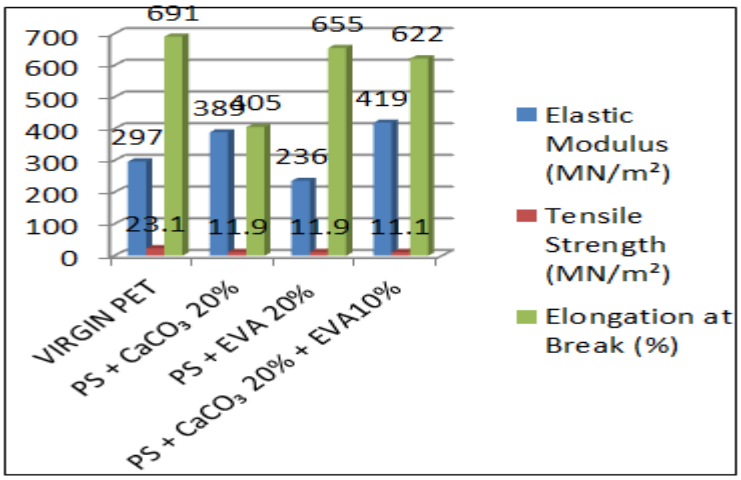

Fig-9. Comparison of Mechanical Properties of the Recycled PET/virgin LDPE to Virgin PET Reprocessed in the Twin-Screw Compounder at 210°C.
Source Is the results of experiment carried out

Fig. 9 shows that with suitable incorporation of anti-oxidant, inert filler and modifier agent, we can achieve good properties of elastic modulus and elongation at break while the tensile strength remain smaller when compare to that of virgin PET. Action against Composition (Virgin LDPE/Recycled Nylon)

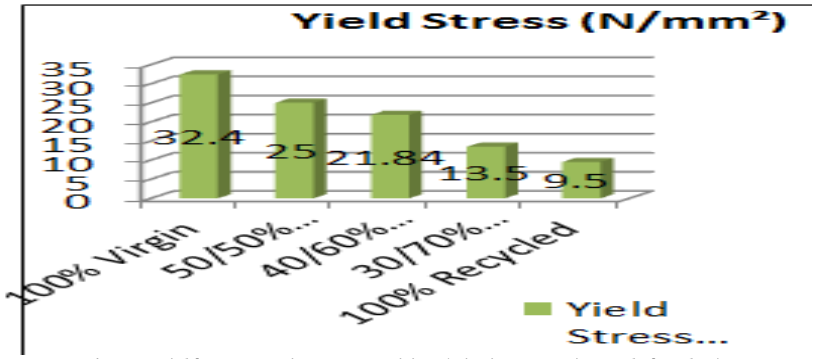

Fig-10. Yield Stressagainst Composition (Virgin LDPE/Recycled Nylon)
Source: Is the results of experiment carried out

Fig. 10 shows that the yield stress required for breaking decreases as the ratio of virgin resins to recycled resins decreases.

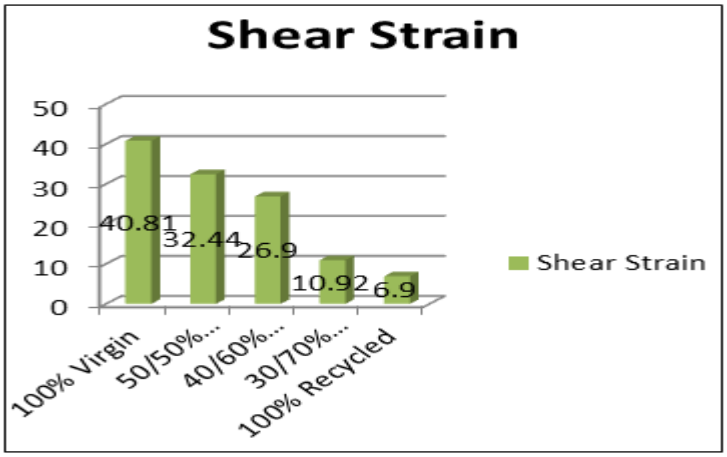

Fig-11. Shear Strain against Composition (Virgin LDPE/Recycled Nylon)
Source: Is the results of experiment carried out

Fig 11 shows that the as the amount of recycled resins in the composition increases, the shear strain decreases.

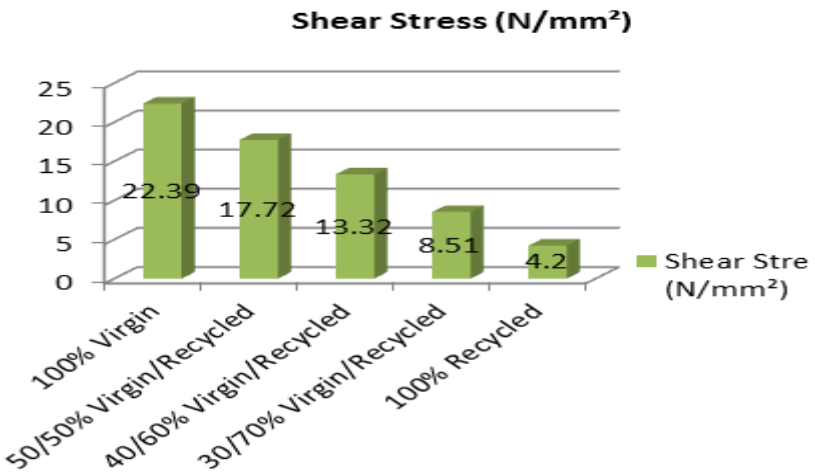

Fig-12. Shear Stress against Composition (Virgin LDPE/Recycled Nylon)
Source: Is the results of experiment carried out

Fig. 12 shows that as the ratio of virgin resins to recycled resins decreases, the shear stress decreases. This implies that the force per unit area require to break a product from such polymer matrix will decrease.

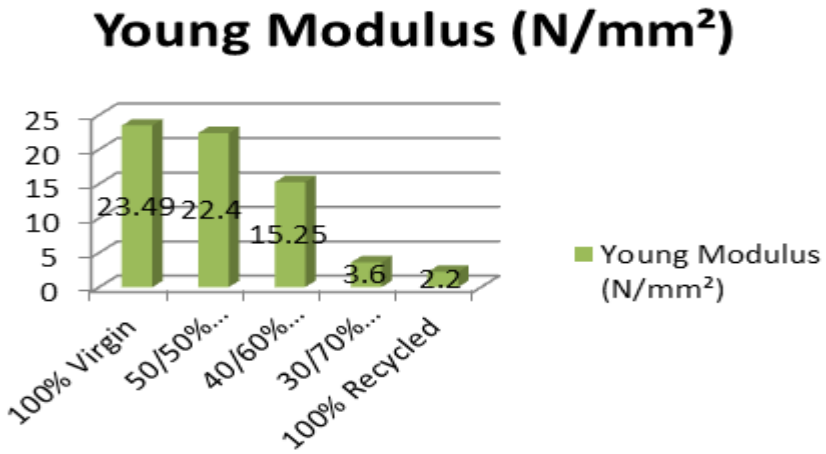

Fig-13. Young Modulus against Composition (Virgin LDPE/Recycled Nylon
Source Is the results of experiment carried out

Fig. 13 shows that as the ratio of the virgin resins to recycled resins decreases, the young modulus or the stiffness decreases.

5. CONCLUSION

This study gave rise to a good recycled material provided that suitable reprocessing machines and optimal processing conditions were adopted. The recycled material can be used to produce some of these, such as carpets, footwear, rugs, pipes, sheets, films, wire covering etc. The use of antioxidants, inert fillers and modifier agents also help greatly, improve some of mechanical properties. The 50% virgin resin/50% recycled materials gave the best product with mechanical properties close to that of the virgin resin.

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Competing Interests: The authors declare that they have no competing interests.
Contributors/Acknowledgement: All authors contributed equally to the conception and design of the study.

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