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ORIGINAL RESEARCH ARTICLE

Influence of Blending on Mechanical Behavior of Low-Density Polyethylene, Polypropylene, Polyvinylchloride

Suleman S. A.[1]* Abubakar Y. M.[2], Aliyu A.[2], Galadima A. I.[2] and Abdelmalik A. A.[2]
[1]Samaru College of Agriculture, Ahmadu Bello University, Zaria, Nigeria.
[2]Department of Physics, Ahmadu Bello University, Zaria, Nigeria.

ABSTRACT

Three thermoplastic polymers, low-density polyethylene (LDPE), polypropylene(PP), and polyvinyl chloride (PVC),were synthesized from their raw pellets.Three blends of 1:1 wt.% of low-density polyethylene/polypropylene, low-density polyethylene/polyvinylchloride, polypropylene/polyvinylchloride, and one blend of 1:1:1 wt.% of low-density polyethylene/polypropylene/polyvinylchloride were produced via compression mould method using Two-roll Mill machine and Compression Mould machine. Using the Tensile Strength Tester machine, the pristine polymer and the blends were cut into dumbbell shapes for mechanical testing. The resultsobtained are 9.8MPa and 67.5% maximum stress and strain, respectively, for LDPE, 29MPa, and 12.4% maximum stress and strain, respectively, for neat PP. 25.8MPa and 35% maximum stress and strain respectively for pristine PVC, 19.2MPa and 44% maximum stress and strain respectively for LDPE/PVC blend, 19MPa and 29% maximum stress and strain respectively for LDPE/PP blend, 27.5MPa and10.75% maximum stress and strain respectively for PP/PVC, 21MPa and 10.4% maximum stress and stain respectively for LDPE/PP/PVC blend. The force at peak and the respective peak elongation are; 85.612N and 0.008387m for pristineLDPE, 344.810N and 0.004810m for pristinePP, 264.976N and 0.005496m forpristine PVC, 188.288N and 0.005980m for LDPE/PVC blend, 174.755N and 0.005109m for LDPE/PP blend, 250.196N and0.004287m for PP/PVC blend, 275.175N and 4.009mm for LDPE/PP/PVC blend. The maximum energies expended to have maximum extension are 0.71802784J (LDPE), 2.04578339J (PP), 1.70308635J (PVC), 1.12596224J (LDPE/PVC),0.8928233J (LDPE/PP), 1.50129025J (PP/PVC) and 1.10317658J (LDPE/PP/PVC). These results show improvement in the mechanical properties of the blends when compared with those of the constituent polymers. It also indicatesthat polymeric properties modification via an immiscible polymer blend is possible and easy to achieve.

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Polymer, pristine, blend, stress, strain, terpolymer, intermolecular forces.

INTRODUCTION

Polymers are macromolecules formed from micro-units (monomers) through a chemical linking process known as polymerization (George, 2021). Polymers can be synthetic, such as polyethylene, polyvinyl acetate, polypropylene, etc., which are formed from petrochemicals or naturally occurring substances such as proteins, cellulose, keratin, etc., obtained from bio sources. Synthetic polymers are classified into thermoplastics; which become malleable when exposed to heat,and thermoset; which hardens when exposed to heat (George, 2021). Polypropylene(PP), Polyvinylchloride (PVC), and polyethylene (PE) form major products of plastics and belong to the polyolefin group. Because of their excellent thermal stability, oil resistance, stiffness, and rigidity, etc., these polymers are largely used as engineering materials in the packaging industry, electrical appliances industry, medical and biopharmaceutical industries, as well as automotive industry (Dikobe & Luyt, 2010).

Polypropylene is a crystalline, strong, very light polymer with good bending resistance and high heat distortion resistance. Being non-polar (containing carbon, hydrogen, and oxygen atoms),polypropylene dissolves in a non-polar solvent. Polar solvents like water, soap solution, alcohol, and wetting agents do not have effect on polypropylene. Being a poor conductor of heat and electricity, polypropylene ranks higher and better in insulating properties amongst plastics. It is also widely used in

Correspondence: Suleman S.A. Samaru College of Agriculture, Ahmadu Bello University, Zaria, Nigeria.
✉ abuzahra2012@gmail.com

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medical devices as it can be heat-sterilized, easy to be processed, and recyclable (Brennan & Day, 2011; TROIA, 2011). Low-Density Polyethylene (LDPE) has a lower density range of about 0.910-0.940g/cm^3 compared to High-Density Polyethylene (HDPE), that has density range of 0.954g/cm^3 and above (Buchalla *et al.,* 1995). This makes the molecules to be loosely packed and less crystalline. LDPE chain has more branching on about 2% of the carbon atoms making it have weaker intermolecular forces due to double carbon-carbon bond (pi-bond) than High-Density Polyethylene (HDPE). It is non-reactive at room temperature except with the action of strong oxidizing agents and some swell-causing solvents. It is flexible with lower tensile strength and higher resilience [5]. Polyvinyl chloride (PVC) is a polymer used widely in medical and food industries for medical devices and radiosterilizable food packaging respectively.

The polymer properties (physical, thermal, electrical)can be improved or modified by adding enhancers such as nano-particles to form composites or combining two or more polymers to form a polymer blend. This is called 'blending' in polymer science and engineering. Blending is easier than synthesizinga new chemical structure to form a new polymer to solve emerging problems(Anjana & George, 2012). Structural modificationsof polymers via blending widen polymers' applications and solve many potential defects associated with a single polymer. Molecular structures and molecular weights are the two areas involved in modification during polymer blending. Sometimes copolymers (polymer that shares similar molecular structures with the two constituent polymers) are used to enhance the modification processes (Murugesan & Scheibel, 2020 and Caren *et al*, 2022). Polymer blends are broadly categorized into three; miscible, immiscible, andcompatible (partially miscible) according to (Sadiku & Ogunniran, 2014)

Attention is now on immiscible polymer blends for commercial application since the base polymers in the blend retain their good individual properties. Some properties (for example, the improvement in impact strength) are only achievable through immiscible polymer blends, as explained in (Kadhim & Kadhim, 2017). An example of the molecular structure of two immiscible polymers blend (A and B) is shown in Figure 1 (Kadhim & Kadhim, 2017; Utracki & Wilkie, 2002).

The industrial or commercial importance of polymers and their increasing demand calls for continuous need and innovations to improve their properties to meet the necessary conditions, demands, and applications. Molecular weight and degree of polymerizability are the most important characteristics of polymer and polymerization reaction that leads to molar mass and chain length distribution (Babker et al., 2018). Polymeric properties can be adapted to satisfy specific needs by altering the atomic composition of the molecular mass or structure that forms the chain. [8-9]. There are also the possibilities of modifying natural polymers with chemicals to achieve desired products(Kuno & Fujii, 2011; Margolis, 2020).

The PP/LDPE blend properties were studied in the ratio of 4:0, 1:3, 2:2, 3:1, and 0:4 wt.%. Adding LDPE to PP shows a decline in the tensile strength, flexural strength, flexural modulus, and hardness. However, there was an improvement in the density of the blends. Superior tensile strength was observed in the 3:1 blend, while preferable flexural strength was observed in the 2:2 blend(Kadhim & Kadhim, 2017). The valorization of two regenerated LDPE samples obtained from dirty wastes blended with PP in the presence of compatibilizer was investigated, and the results show thatblending has considerably enhanced the performance properties of the regenerated LDPE (Guerfi & Belhaneche-Bensemra, 2014). Long-term strength of five composites of plastic waste containing LDPE, HDPE, PP, and PS was studied.The long-term strength was determined experimentallyby tensile creep to fracture;it was observed that the 50%wt. PS composites had the greatest strength among the tested samples. Nonetheless, it has a brittle fracture, and its calculated value of long-term strength did not agree with the experimental value (Krastev *et al.,* 2013). PP/LDPE blend was studied through injection moulding performed under different injection temperatures. It was observed that the processing temperatures contributed significantly to the behavior of the blends. ThePP/LDPE blend containing 25wt.% LDPE shows degradation in mechanical properties similar to that caused by zero degree Celsius (Strapasson *et al.,* 2005). The plastic consumption rate has increased geometrically in the recent decades with 359 million tons of plastics produced in 2020 alone (Caren, *et al,* 2022). This huge demand for plastics has attendant effect on the plastic wastes generation because most of them are single-use and also put pressure on the primary source polymers (Caren, *et al,* 2022). Polymer blending does not just improve the properties of polymer but also reduce over dependence on pristine polymers, any effort towards achieving this cannot be over emphasized. In this work, three common polymers (Low Density Polyethylene, Polypropylene and Polyvinylchloride) were selected for preparation and mechanical characterization of blends containing two and three polymers to investigate the mechanical properties of the polymers and polymer blends for any useful applications.

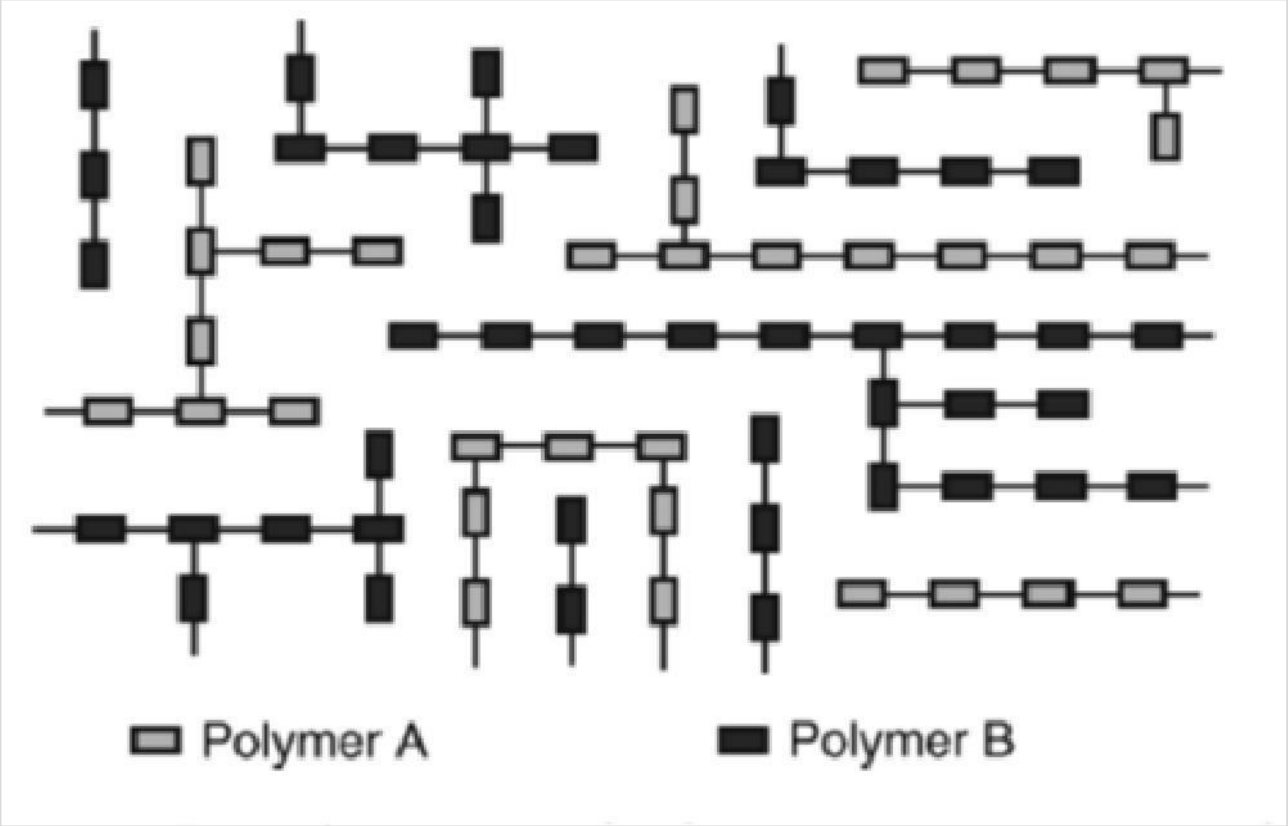


Figure 1: Schematic molecular structure of polymer blends.

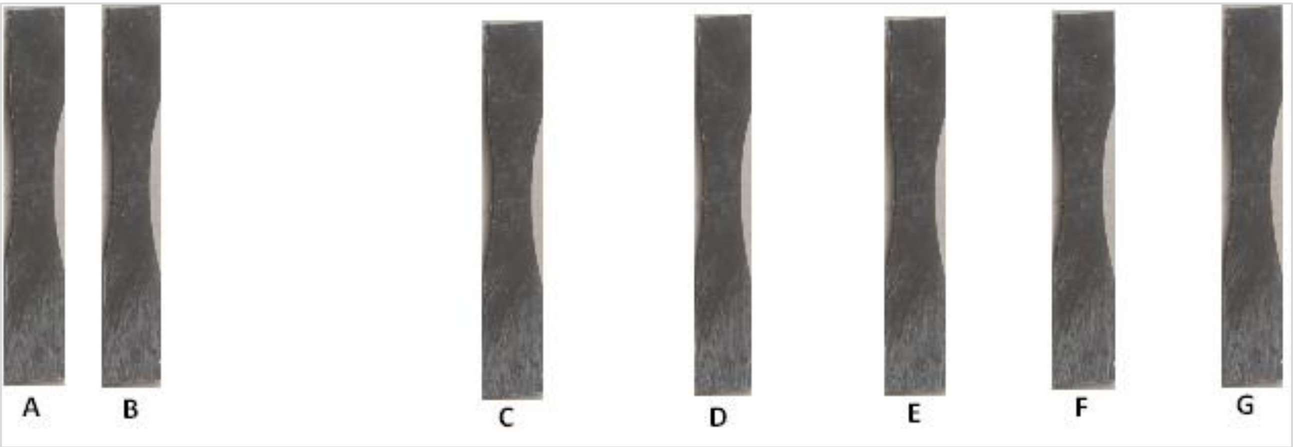
MATERIALS AND METHOD

Sample preparation: Getting a single solvent to dissolve the two or three polymers together is a big challenge, so also drying out of the solvent before characterization. It is in this light that compression mould method was chosen against the dissolution mould method. Most previous works done used extrusion method to get the polymers melted and mixed together before applying the compression mould for the casting (Caren, *et al*, 2022) but Two-roll Mill machine was used in this work to melt and mix the polymer pellets together before casting via compression mould. The detail of the sample preparation is explained below;

Pristine polymer:The three polymer samples, Low-Density Polyethylene (LDPE),Polypropylene (PP), and Polyvinylchloride (PVC), were dried in the electric oven at 35°C for 25 mins to remove any moisture from the samples. Subsequently, the samples were weighed and poured into the Two-roll Mill machine to turn the pellets into a paste for moulding. The front and rear rollers temperatures were set to 150°C for neat LDPE and PVC respectively. For pristine PP,the temperature was set to 200°C because it has a higher melting temperature. The front and rear roller speeds were set to 4.629rpm and 0.854rpm, respectively. Immediately, the polymer paste was placed in a 1mmmould and placed inside the compression moulding machine at 150°C and 2.5MPa for 3 mins.Finally, the moulded polymer was transferred tothe cooling apartment of the machine, where it was cooled at 0°Cand 2.5MPa for 2 mins. The 16cm by 11cm flat sheet of neat polymers were cut into dumbbell –shape for mechanical tests.

To prepare the blends of two polymers, dry samples were weighed in the ratio of 1:1 wt.% and poured into the Two-roll Mill machine at 150°C for both front and rear rollers; the rolling speed of 4.629rpm and 0.854rpm was maintained for front and rear roller respectively. Finally, the machine melts and mixed the two polymers together to form a paste. Later on, the paste was run several times to ensure the homogeneity of the blend before putting it in the mold. Meanwhile, the mould was placed in the compression moulding machine at 150°C and 2.5MPa for 3 mins and cooled under the same pressure. At the end, 16cm by 11cm flat sheet of the blend produced was cut into a dumbbellshape for analysis.

In preparing the terpolymer, dry samples of LDPE, PP, and PVC were weighed in the ratios 1:1:1 wt.% and poured into the Two-roll Mill machine at 150°C; the Rolling speed of both the front and rear roller was4.629rpm and 0.854rpm respectively. Thegap between the two rollers was maintained at 0.1mm. At that point, the machine melted and mixed the three polymers together to form a paste. Eventually, the paste was rolled over repeatedly for 30 times on the rollers to ensure homogeneity before putting it into the 1mm mould. Just then, the mould was placed in the compression moulding machine at 150°C and 2-5MPa for 3 mins. It was then moved to cooling apartment of the machine at 2.5MPa and 0 °C.Lastly, a 16cm by 11cm flat sheet blend produced was cut into a dumbbell-shape for test.



Figures 2: Dumbell-Shape Sample specimen A-G

Table 1: Sample Description

s/n	Samples	Description
1	A	Low-density polyethylene (LDPE)
2	B	Polypropylene (PP)
3	C	Polyvinylchloride (PVC)
4	D	LDPE/PP Blend
5	E	LDPE/PVC Blend
6	F	PP/PVC Blend
7	G	LDPE/PP/PVC Blend (Terpolymer)

Sample characterization:

The tensile strength of each pristine blend and the terpolymer samples was determined using a double-column tensile strength machine with a maximum loading capacity of 100 kN. The test sample specimens were prepared by cutting the polymers into a dumbbell-shape with the gauge section between the two edge-bell shapes. The specimenis 100 mm long, 15mmwide,and 1mmthick, while the gauge section length and width are 40mmand 10mm, respectively. Three specimens were produced from each of the pristine blend and the terpolymer samples. Eachspecimen was gently and properly placed vertically inthe test machine,and the dumbbell edges were held by the jaws of the lower and upper tensile grips of the test machine. Subsequently, Force was appliedto the specimen till deformation and breaking (failure) occurred within the gauge section. The test machine was controlled via a coupled computer that uses tensile strength analyzer software known as TM2101N_RXVersion (V$_{8-38}$).

RESULTS AND DISCUSSIONS

Pristine samples: Figure 3 shows the stress results plotted against the strain for thepristine polymer samples.

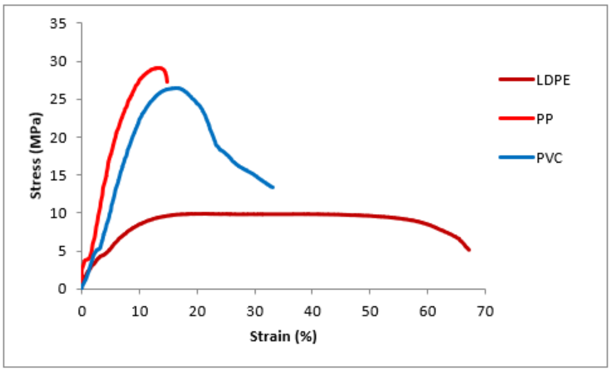


Figure 3: The stress-strain curve for the three pristine polymer samples

The stress-strain curve for the pristine LDPE polymer shows a good linear behavior up to a maximum stress of 9.8MPa and strain of 18.5%, indicating a small but good Young's modulus. This is possibly due to the weaker intermolecular forces between the molecules suggesting that LDPE molecular structures have branching (aromatic chain) with weak C=C (pi-bond) (Brennan & Day, 2011; TROIA, 2011). This also accounts for its low-impact strength. After attaining the maximum stress of 9.8MPa (between the strain of 18.5% and 45%), the curve remains flat, indicating no significant increase in stress as the strain increases.This implies that a very small force applied produced a large elongation and by extension, large strain. Beyond this point (45% strain) on the curve, there is a decline in the stress while the strain increases up to maximum of 67.5% before breaking. This implies that the pristine LDPE polymer is resilient and flexible (having good plastic deformation) but brittle looking at the low stress (9.8MPa) that is responsible for its deformation and breaking. This is further supported by the lowest value of maximum energy expended at breaking (fig. 5). The data in Table 2 and the properties of LDPE given in (Kadhim & Kadhim, 2017 and Caren, *et al* 2022) further supports this finding. For the pristine PP, the stress-strain curve (fig. 3) shows a good linear relation up to a maximum stress of 29 MPa and a strain of 12%, undergo short plastic deformation before breaking at a strain of.15.5%. This indicates that PP has a considerably high Young's and bulk moduli. Also it has high level of impact strength withstanding up to 369.809 N impact forceand 2.04578339 J of energy to produce 0.005532 m extension (Table 2 and Fig. 5) before breaking. This shows that PP has relatively high intermolecular force of attraction(C-C sigma bond) suggesting a tough, flexible and more resilience plastic (Caren, *et al,* 2022). These properties make it suitable in medical devices and packaging industries. The stress-strain curve for the pristine PVC(fig. 3) shows almost linear relation up to a maximum stress of approximately 27 MPa (18.5% strain). This implies that PVC like PPhas relatively high Young's and bulk moduli because of its strong intermolecular forces (C-C sigma bond). It undergoes relatively long plastic deformationbeforefinally breaking at 32.5% strain). It withstands a maximum force of 265.858 N and requires 1.70308635 J of work to produce 0.006406 m extension before breaking (see Table 2 and Fig. 5). All these descriptions make PVC a good plastic that is resilient, flexible and tough(Kadhim & Kadhim, 2017). It also has good ductilitywith high impact strength.The mechanical properties of PVC are very similar to that of PP except that PVC is more ductile than PP, as seen from their maximum strains.This isprobably the reason that makes PVC the number one choice of polymer for packaging industry and for electric cable insulation.

Table 2: Peak data (Force and Elongation) and the corresponding Energy expended

S/N	Sample	Force @ Peak Elongation (N)	Elongation @ Peak (m)	Energy Expended (J)
1	LDPE	85.6120	0.008387	0.71803
2	PP	369.8090	0.005532	2.04578
3	PVC	265.8580	0.006406	1.70309
4	LDPE/PVC	188.2880	0.005980	1.12596
5	LDPE/PP	174.7550	0.005109	0.89282
6	PP/PVC	350.1960	0.004287	1.50129
7	LDPE/PP/PVC	275.1750	0.004009	1.10318

Two-Polymer Blends and the Terpolymer

The results of the characterization of the blends and the terpolymer are shown in Figs. 3,4 and Table 2. The stress-strain curve for the LDPE/PVC blend shows a good linear stress-strain relation up to a maximum stress of 19.2 MPa and strain of about 15%, indicating a good and relatively high Young's and bulk moduli. Also, the LDPE/PVC blend undergoes long plastic deformation before breaking at a strain of 49%. The high Young's and bulk modulus imply that the intermolecular forces of attraction in the LDPE/PVC blend are stronger than in the constituent polymer leading to an enhanced impact strength in the blend as compared to the base polymer (Kadhim & Kadhim, 2017). Thus, there was improvement on the tensile stress of the blend compared to the pristine LDPE and the tensile strain of the pristine PVC. The improved strain enhanced the toughness, flexibility, resilience, and ductility of the LDPEPVC blend as compared to the individual base polymers (LDPE and PVC).Also, the force at peak and the maximum energy expended are higher for the LDPE/PVC blend compared to the pristine LDPE, but elongation at the peak is lower. This is because the LDPE/PVC blend is tougher than the LDPE. Therefore more work is needed to produce the extension. Although the force at peak and the maximum work done are higher for the pristine PVC than that of the LDPE/PVC blend, the difference is not significant(Fig. 4 and Table 2). The stress-strain curve for the LDPE/PP blend (Fig. 4) shows a goodlinear relation up to a maximum stress of about 19.2MPa and a strain of about 12.5%, indicating a plastic with good impact strength, Young's and bulk moduli.The maximum stress of the LDPE/PP blend (19.2 MPa) doubles that of the pristine LDPE (9.8M Pa)but is lower than that of the pristine PP (29.5 MPa). The maximum strain of the LDPE/PP blend (30%) is lower than that of the pristine LDPE (67%) but higher than that of the pristine PP(12.4%). The LDPE/PP blend shows a better tensile stress compared to that of the constituent pristine LDPE and better tensile strain compared to that of the constituent pristine PP. The improved tensile stress indicates that the intermolecular forces in the LDPE/PP blend is much stronger than that of the pristine LDPE, accounting for the improved Young;s and bulk moduli, high impact strength in the blend as compared to the pristine LDPE, but is lower than that of the pristine PP. The peak force for the LDPE/PP blend (Table 2) is higher than that of the pristine LDPE but lower than that of the pristine PP (Caren, *et al,* 2022). Meanwhile, the elongation at peak force is comparable for the LDPE/PP blend and the pristine PP but lower than that of the neat LDPE (Table. 2). Much work is also done to have maximum extension on pristine PP than the LDPE/PP blend but comparable for the neat LDPE (Fig. 5).All these agrees with the conclusion of (Kadhim & Kadhim, 2017) that 1:1 wt.% of the PP/LDPE blend shows better mechanical properties than any other ratios.

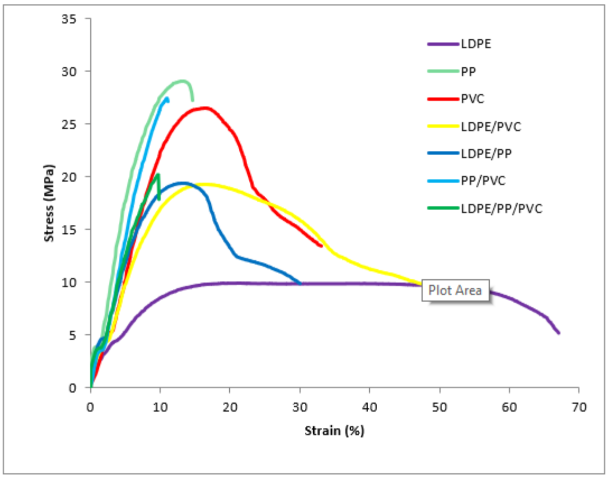


Figure 4: The Stress-Strain curves of the neat Polymers, blends and the Terpolymer

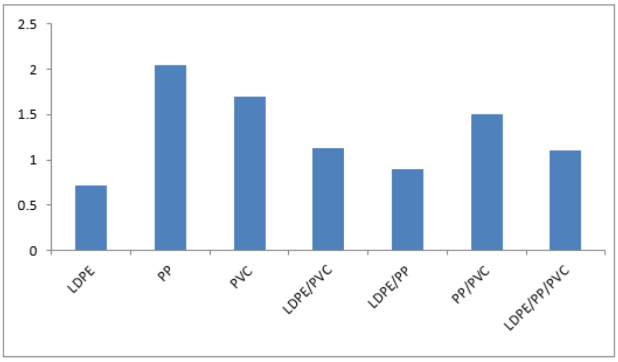


Figure5: Bar chart showing the energy expended at peak elongation of the samples

The stress-strain curve for the PP/PVC blend shows a good linear relation up to a maximum stress of 27.5 MPa and 10.75% strain, indicating very good and high impact strength, Young's and bulk moduli for the PP/PVC blend, implyingvery strong intermolecular forces of attraction between its molecules like the base polymers. Beyond this point, the PP/PVC blend undergoes short plastic deformation before breaking at 10.75% strain. There is a very close similarity between the stress-strain curves of the PP/PVC blend and the base polymers (PP and PVC), especially before attaining maximum stresses. This shows that, to a large extent, there is a close similarity in the mechanical properties of the PP/PVC blend as compared with those of the base polymers. The maximum stress of the PP/PVC blend (27.5 MPa) is comparable to that of the pristine PP (29 MPa) and the pristine PVC (27 MPa). Also, the breaking point (maximum strain) of the PP/PVC blend (10.75%) also compares well with that of the pristine PP (12.4%)but lower than that of the pristine PVC (35%). The peak force for the PP/PVC bend (350.196 N) compares well with that of the pristine PP (369.809 N) but higher than that of the pristine PVC (265.858 N). The elongation at peak for the PP/PVC blend (0.004287 m) compares well with that of the pristine PP (0.005532 m) but is slightly lowerthan that of thepristine PVC (0.006406 m). Meanwhile, the work done to have maximum extensions in the PP/PVC blend is slightly comparable to those of the base polymers (see Table 2 and Fig. 4). The base polymers (PP and PVC) have very close physical and mechanical properties;they are also close in industrial applications. Their blend, especially (1:1 wt.%), shows a very close similarity in mechanical behaviorto the base polymers, PP and PVC are mostly used for packaging in industries, electrical insulations as well as in the medical and the biopharmaceutical industries for the production of syringes, personal protective equipment (PPE) like hand gloves, coats, head gears and boots (Buchalla *et al.*, 1995; Guerfi & Belhaneche-Bensemra, 2014). The PP/PVC blends can arguably be used for all these applications.

The stress-strain curve for the terpolymer (LDPE/PP/PVC blend) shows a good linearbehavior up to a maximum stress of 20.5MPa and strain10% implying a good and high Young's and bulk moduli. It also indicates that the intermolecular force of attraction between the molecules is strong and high. The terpolymer underwent short plastic deformation before breaking at a strain of 10.2%. The stress-strain curve shows a similar behaviorto that of the pristine PP, PVC,and LDPE/PVC, LDPE/PP, PP/PVC blendsbefore reaching the maximum stress implying similar plastic behavior. The maximum stress of the terpolymer compares well with that of the LDPE/PP and LDPE/PVC blend, higher than that of the pristine LDPE but lower than those of the pristine PP, PVC, and PP/PVC blend. The peak forceof the terpolymer(275.175 N) is lower than those of the pristine PP and PP/PVC blend, higher than those of pristine LDPE, LDPE/PP, and LDPE/PVC blend but compares well with that of the pristinePVC (Table 2). Meanwhile, the peak elongation also compares well with that of the PP/PVC blend but slightly lower than that of the pristine PP polymer. The work done to have maximum extension of the terpolymer (1.10317658J) is comparable to those of LDPE/PP and LDPE/PVC blends, higher than that of the pristine LDPE but lower those of the pristine PP, PVC, and PP/PVC blend

CONCLUSION

The pristine LDPE, PP, and PVC exhibited mechanical properties that are in line with literature predictions (McCrum et al., 1997).The polymer blends (LDPE/PP, LDPE/PP , PP/PVC,and terpolymer) are immiscible and show good plastic behaviours leading to an enhanced mechanical properties. This agrees with the result of (Caren, *et al*, 2022) and also validate the use of the Two-roll Mill machine in place of extruding machine for melting and mixing polymer pellets together. It also demonstrates that blending provides a viable option for enhancing and modifying polymeric properties. Mixing of LDPE with PP and PVC has improved the strain of the resulting blends. The LDPE/PP, LDPE/PVC, and the terpolymer show almost the same maximum stress, implying one can be use in place of other where high' impact strength' is required in the application, this will reduce over dependence on the neat polymers thereby reducing quick depletion of primary sources of polymers (Caren, *et al,* 2022). The PP/PVC blend can be use in any applications that requires either PP or PVC, even with a better performance. PP is the toughest of the pristine polymers, while PP/PVC is the toughest of the blends. The polymer blends show improvement in mechanical properties over the base individual polymer (Guerfi & Belhaneche-Bensemra, 2014; Kadhim & Kadhim, 2017), affirming that opportunities abound in enhancing and modifying polymeric properties via blending.

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