

Mechanical Properties of Polyvinyl Chloride and Polypropylene Hybrid Polymeric Nanocomposites for Structural Applications

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ABSTRACT

In this work, mechanical properties for three types of polymeric blends and polymeric composites were fabricated and evaluated. The first group was prepared from (polyvinyl chloride: polypropylene (PVC: PP)) in different ratios of polypropylene (5, 10 and 15%). The second group was prepared by adding 1% ethylene propylene diene monomer (EPDM) to the first group samples. Similarly, the third group was prepared by adding 1% acrylonitrile-butadiene-styrene (ABS) to the first group samples. All samples were prepared by melt blending technique using a twin-screw extruder. The optimum sample from the three groups was reinforced in different ratios of titanium dioxide (TiO₂) nanoparticles. The results of mechanical properties show that the polymer blend (PVC-PP-EPDM) has higher values in compressive strength, flexural modulus, impact strength and fracture toughness, whereas the polymer blend (PVC-PP-ABS) has higher values in flexural strength. The highest compressive strength, flexural modulus, impact strength and fracture toughness were 240 MPa, 2.5 GPa, 69.7 kJ/m² and 13.2 MPa√m for ternary polymers blend (94%PVC: 5%PP: 1%EPDM), whereas the high value of flexural strength was 78 MPa for ternary polymer blend (94%PVC: 5%PP: 1%ABS). Addition of TiO₂ nanoparticles has led to the improvement in mechanical properties of prepared composites. Morphology analysing pointed out that the composites have a homogeneous structure formation, as a result of the high efficiency for each of TiO₂ nanoparticles and EPDM in a composite.

Keywords: Mechanical Properties, PVC, PP, ABS, EPDM, Extruding and Polymer Blend.

1. INTRODUCTION

The benefit of blending of polymers is to produce new materials with improved properties differ from the properties of the individual components, modification in processing conditions and reduction in cost [1]. Polyvinyl chloride (PVC) is one of the most common article polymers, which has broad properties range, low cost, and has been widely used in building construction, automobile, biomedical material, pipe, and, packaging fields [2]. Due to low thermal stability, the processing of PVC in the raw form using heat and pressure resulted in severe degradation of the polymer. Therefore, special stabilizer systems are often used with PVC to retard degradation [3]. Recently, various efforts have been made to improve the thermal stability and mechanical properties of PVC [4-5]. Malysheva *et al.* [6] investigated the influence of flexible and rigid segments of elastomers on a compatibility, structure and mechanical properties of poly(urethane-urea)/(polyvinyl chloride) blends. Morphology studies have shown the effect of interfacial interactions on size of thermoplastic phase dispersed within elastomer matrix and this improved the mechanical properties, especially tensile properties.

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Klapiszewski *et al.* [7] prepared an advanced SiO₂-lignin hybrid material as a novel PVC filler. The results showed that the introduction of hybrid filler into the PVC matrix results in a homogeneous structure of the composites and functional properties, especially thermal stability. Rostam *et al.* [8] investigated the mechanical properties of PVC polymer under heating and cooling conditions. It was observed that the strength of the tested samples decreases with the increasing heating temperature. Meanwhile, the cooling environments provide a significant increase in the strength of the material. Hezma *et al.* [9] prepared nanocomposites based on polyurethane and PVC loaded with low contents of multi-walled carbon nanotubes (MWCNTs) using solution casting technique. The results showed that the glass transition temperature (T_g), melting point (T_m) and degradation temperature (T_d) of the samples were increased with an increase of different concentrations of MWCNTs. Nowadays, the development of biomaterials has become a primary goal for material engineers. Using materials from natural sources gives an option to modify PVC structures and properties. Modification of PVC/Corn cob blends was investigated. The PVC/Corn cob blends also have increased impact strength and the other mechanical properties were improved as well [10]. In a recent study Salih *et al.* [11], they noticed an improvement in mechanical properties when added with microparticles (graphite, alumina (Al₂O₃) and copper (Cu) at different volumetric fractions (0, 2, 4 and 6%) as reinforcement materials of the binary polymer blend (HDPE: PVC) to produce hybrid composite materials by friction stir processing (FSP) technique. Another study relied upon the features possessed by PVC material, where the glass fibre filament was coated with PVC material at the extruder in filament form. The filament material produced was woven with a weaving loom then pressed at 165°C and 2.5 MPa of pressure. Tensile tests were carried out on the samples prepared and higher mechanical strengths were obtained by increasing the fibre volume [12]. Wood-plastic composite materials are extensively used in the building industries. PVC – due to its compatibility with the natural fibres, less cost, low maintenance, good durability, chemical and flame resistance has become more appropriate material to build structures and in other construction works [13].

In this work, the mechanical properties were compared for three types of polymeric blends, which are binary polymer blend (polyvinylchloride (PVC)-polypropylene (PP)) and two ternary polymer blends (PVC- PP- Acrylonitrile butadiene styrene (ABS)) and (PVC-PP-ethylene propylene diene monomer (EPDM)). In addition, titanium dioxide (TiO₂) nanoparticles were used as reinforcing particles to improve the mechanical of optimum polymeric blends.

2. EXPERIMENTAL PART

2.1 Materials

PVC, PP, ABS and EPDM used in this study are commercial products. Polyvinylchloride is white powder "type k-70". PVC has been produced by Bandar Imam Center, Iran. Heat stabilizer was used primarily to inhibit thermal degradation of PVC during processing. The stabilizer (Dibasic Lead Stearate) and lubricant (stearic acid) were used with a ratio of 1.5 and 0.5 parts for (100 parts) by weight for PVC respectively. Polypropylene was supplied from Sabic Company, Saudi Arabia type "520 LPP", has a melt flow index of (10 (g/10 min)) and E-modulus (1.6 GPa). Acrylonitrile Butadiene Styrene (ABS) was provided from Basf Company with trade name URTAL A12 /ENICHEM and has a melt flow index of (26 (2.5 gm/ 10 min) at 200°C) and density (1.05 mg/m³). Ethylene Propylene Diene Monomer (EPDM) EPDM 245 was produced from Sabic Company, Saudi Arabia. Titanium dioxide (TiO₂) nanoparticles were used as a reinforcement material, it was produced from Nano Shel company/ USA. Atomic force microscopy (AFM) –scanning probe microscope (CSPM) was used to measure the average particles size of TiO₂ nanoparticles that was (65.91 nm), the particles size distribution is shown in Table 1 and Figure 1.

Table 1 Particle size analysis of titanium dioxide powder as received by AFM test has an average diameter of 75.18 nm

Diameter (nm)<	Volume (%)	Cumulation (%)	Diameter (nm)<	Volume (%)	Cumulation (%)	Diameter (nm)<	Volume (%)	Cumulation (%)
30.00	3.83	3.83	60.00	6.22	43.54	90.00	7.18	82.30
35.00	6.70	10.53	65.00	3.83	47.37	95.00	3.35	85.65
40.00	6.70	17.22	70.00	7.18	54.55	100.00	8.13	93.78
45.00	5.74	22.97	75.00	6.70	61.24	105.00	3.35	97.13
50.00	7.66	30.62	80.00	8.13	69.38	110.00	2.87	100.00
55.00	6.70	37.32	85.00	5.74	75.12			

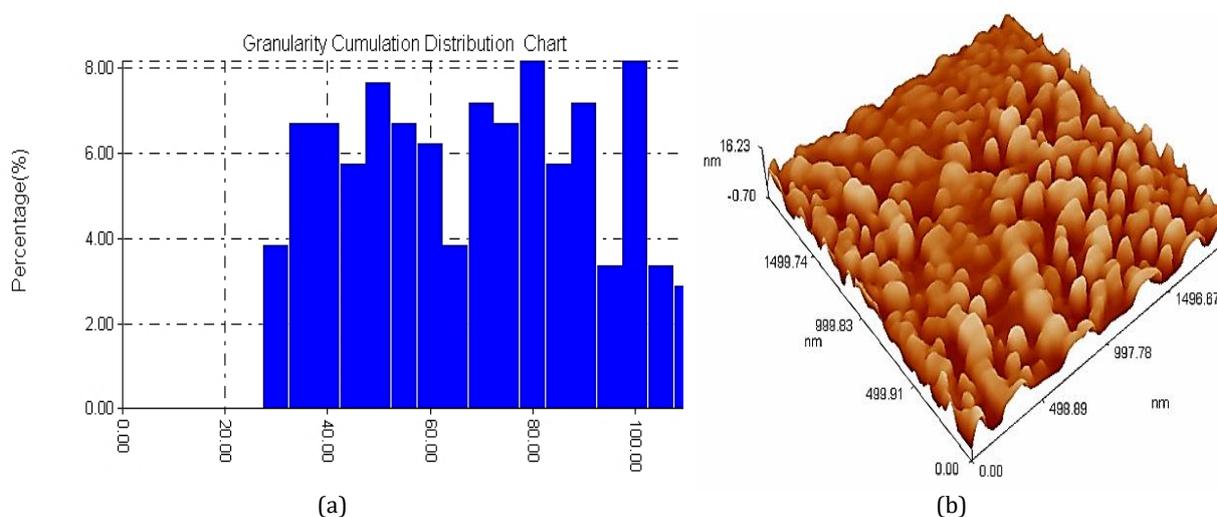


Figure (1). AFM test of titanium dioxide powder nanoparticles with average diameter 65.91 nm, where (a) granularity cumulation distribution chart of titanium dioxide powder, and (b) three-dimensional (XYZ) AFM pictures for titanium dioxide powder.

2.2 Preparation of Samples

Three types of the polymer's blends were prepared according to the formula (PVC: X%PP), (PVC: X%PP: 1%ABS) and (PVC: X%PP: 1%EPDM) with selected weight ratios for PP are (5, 10 and 15%). The samples of polymeric nanocomposites were prepared according to the formula ((94%PVC: 5%PP: 1%EPDM): X%TiO₂) with selected weight ratios of TiO₂ are (0, 1, 3, 5 and 8%). For optimum distribution, the polymer in pellet form and nanoparticle were mixed in a dry condition at room temperature for 30 minutes by a mill made of porcelain material. The forming process was carried out using a twin-screw extruder, with a screw L/D of 30:1. The blending temperature profiles on the extruder for three zones (feed zone, compression zone and melting zone) are 175°C, 165°C and 160°C respectively with the screw speed of 50 rpm. Plates with dimensions (500×40×5 mm) were produced, then cut according to international standard specifications American Society for Testing and Materials (ASTM) for each test.

2.3 Test Methods

Fourier transform infrared spectrometer FTIR (model (TENSOR 27), Bruker Optics Company, Germany) was used to characterize the polymer blend according to ASTM E1252 [14]. It is

equipped with a room temperature deuterated triglycine sulfate (DTGS) detector, mid-IR source 4000 to 400 cm^{-1} and a KBr beam splitter.

For the compression test, the samples were prepared according to ASTM-D 695 [15] using the compression test machine (model WDW200E, made in China). The load was applied gradually to the longitudinally fixed sample at a velocity of 5 mm/min until the sample failed. Samples for the tensile test were prepared according to ASTM-D 638 [16] by using the universal testing machine (model WDW 200 E, made in China) with a velocity of 5 mm/min. A three-point test instrument (model WDW 200 E, made in China) was used to test the bending behaviour according to ASTM D-790-78 [17], the load increasing gradually on the middle of the sample with a constant velocity of 5 mm/min until the failure of the sample occurs. Impact test instrument (model XJU-22, supplied from Time group Inc.) was used to measure the impact strength according to ASTM ISO 179 [18]. All the above-mentioned tests were conducted at room temperature.

Morphology test was done to analyse the fracture surface morphology of polymeric blend and nanocomposites samples by using Scanning Electron Microscope (SEM) model (TESCAN VEGA-SB) made in Belgium. All samples were coated with gold to achieve good electric conductivity [19].

3. RESULTS AND DISCUSSION

3.1 FTIR Spectrum

Fourier Transform Infrared Spectrometer (FTIR) test was done in the range of 400-4000 cm^{-1} for polymers blends (PP-PVC) before and after addition of ABS or EPDM. The FTIR spectrum of neat PVC polymer is shown in Figure 2 where the spectrum is quite similar as reported in [20]. Asymmetric stretching bond of C-H is obtained at 2923.96 cm^{-1} while the symmetric stretch bond of C-H at 2854.17 cm^{-1} wave number. The peaks around 1400 cm^{-1} are assigned to C-H aliphatic bending bond. The peak at 1333.54 cm^{-1} is attributed to deformation vibration symmetrical of CH-Cl bond, as well as the peak at 1258.05 cm^{-1} is attributed to the bending bond of C-H near Cl, twisting CH_2 at 1199.04 cm^{-1} , the stretching vibration of C-C at 1048.72 cm^{-1} , and rocking vibration of CH_2 at 962.38 cm^{-1} . Finally, peaks in the range of 600-650 cm^{-1} correspond to C-Cl stretching vibration mode at 634.89 cm^{-1} and 604.67 cm^{-1} [21].

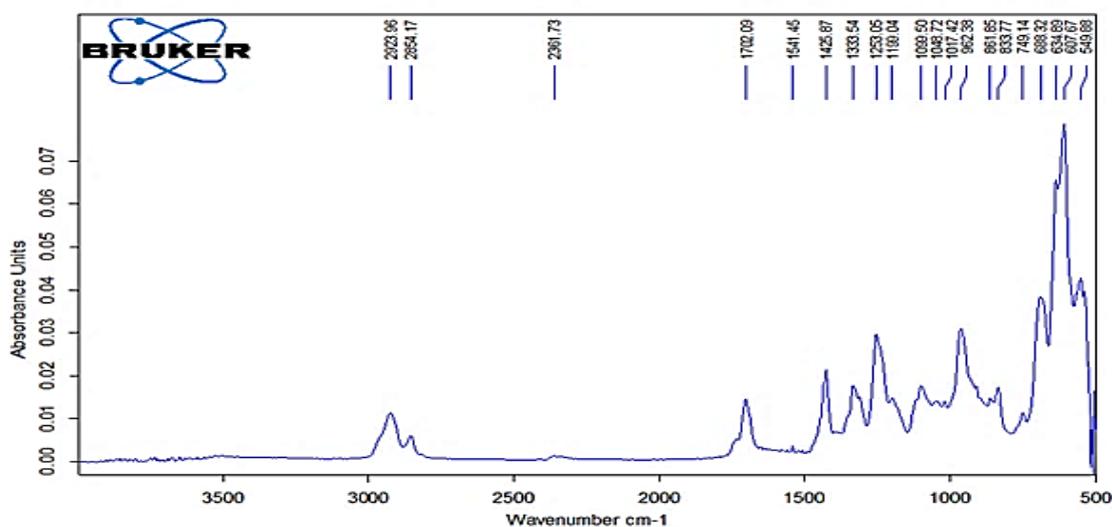


Figure 2. FTIR spectrum for neat PVC polymer.

The spectrum for ABS copolymer and EPDM rubber as received were shown in Figure 3(a) and 3(b), respectively. From the absorbance spectrum of the ABS in Figure 3(a), that the C-O stretching vibration at 1263.52 cm^{-1} and 1011.90 cm^{-1} wave number, and the unsaturated groups from the polybutadiene phase of ABS correspond to the peak of trans-(1,4) 964.76 cm^{-1} , and vinyl-1,2 group at 910.22 cm^{-1} , the styrene C=C stretching vibration (benzene ring vibrations) at 1492.32 cm^{-1} and 1449.41 cm^{-1} and the absorbance spectrum is similar to that reported in [22]. The absorbance bands that characterize the EPDM rubbers (Figure 3(b)) attributed to vibrational modes: asymmetrical stretching of the CH_2 group at 2919.19 cm^{-1} and symmetrical stretching band at 2850.29 cm^{-1} , as well as, asymmetrical and symmetrical deformation bending of CH_3 at 1462 cm^{-1} respectively and in plain bending or rocking of CH_2 at 747.20 cm^{-1} . All the characteristics peaks for this spectrum are similar to that reported by [23].

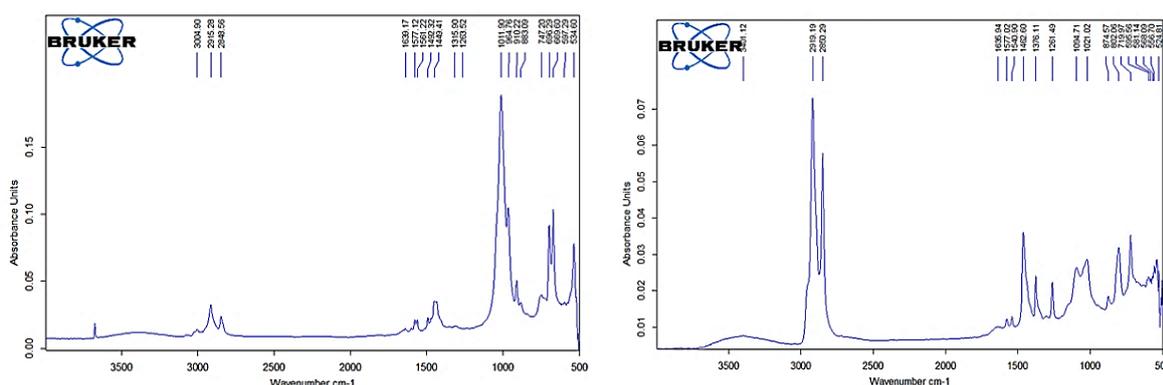


Figure 3. FTIR spectrum for (a): ABS copolymer and (b): EPDM rubber.

The infrared spectra of binary polymer blend (PVC: 5% PP) and ternary polymers blends (94%PVC: 5%PP: 1%ABS) and (94%PVC: 5%PP: 1%EPDM) are shown in Figure 4. All the characteristic vibration bonds for each of PVC, PP, ABS and EPDM appeared in the FTIR spectra for polymer blends (PVC: 5%PP: 1%ABS) and polymer blends (PVC: 5%PP: 1%EPDM) are shown in Figure 4. The main characteristic vibration band for neat PVC present at 610.68 cm^{-1} , hence, confirmed the presence of C-Cl stretching band vibrational mode [21]. So, for the blends prepared with compatibilizer ABS or EPDM elastomer do not reveal a new peak, this means that a new isolated phase in these polymer blends is not formed and it is can be assumed that ABS or EPDM is located at boundaries between PVC and PP [22].

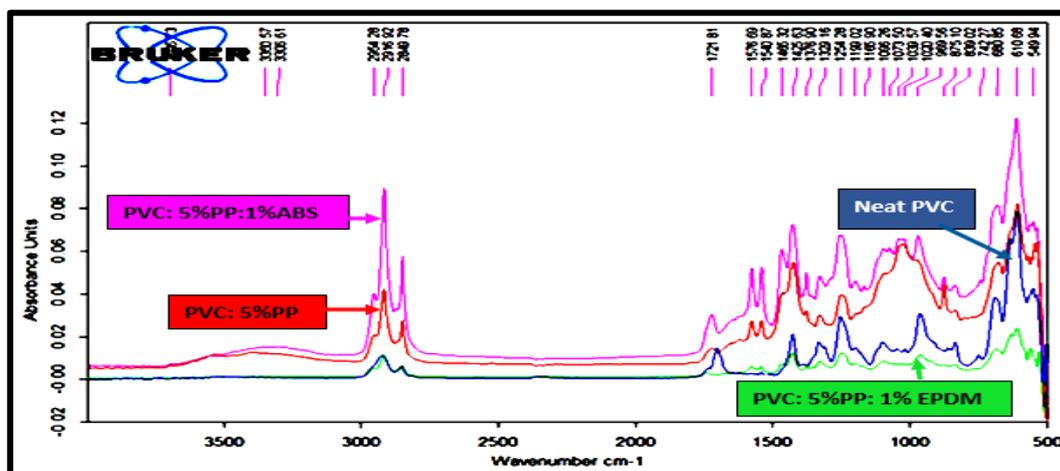


Figure 4. FTIR spectrum for neat PVC and FTIR spectra of binary polymer blend (PVC: 5% PP) and ternary polymers blends (94%PVC: 5%PP: 1%ABS) and (94%PVC: 5%PP: 1%EPDM).

Figure 5 shows the FTIR spectra of nanocomposites [(94%PVC: 5%PP: 1%EPDM): X%TiO₂] as a function of TiO₂ content (3% and 8%) in composite. These spectra are similar to that of neat PVC and ternary polymer blends (94%PVC: 5%PP: 1%EPDM) spectrum and there are no significant differences between these spectra, except the intensity for all characteristic peak of polymer blend nanocomposites [(94%PVC-5%PP-1%EPDM): X%TiO₂] which have lower peaks intensity than their counterparts of neat PP and base polymer blend (94%PVC-5%PP-1%EPDM). All the characteristic vibration bands for PVC and PP, as well as, EPDM rubber, were observed in FTIR spectra of the nanocomposites [(94%PVC:5%PP:1%EPDM): 3% or 8% TiO₂] that are shown in Figure 5. The peak at 1464.32 cm⁻¹ confirms the presence of asymmetric, in plane CH₃ bending and at 1168.06 cm⁻¹ attributed to CH₃ wagging and peaks at 997.22, 958.43 and 840.34 cm⁻¹ are attributed to CH₃ rocking, CH₂ rocking and C-C stretching, respectively [21]. The main characteristic vibration band of neat PVC that presents at 610.68 cm⁻¹ confirms the presence of C-Cl stretching vibration mode as mentioned in [21]. The absorption peaks at (680.69 and 678.67 cm⁻¹) and 535.87 cm⁻¹ belong to titanium dioxide bonds for (Ti-O and Ti-O-Ti bonds), respectively [24].

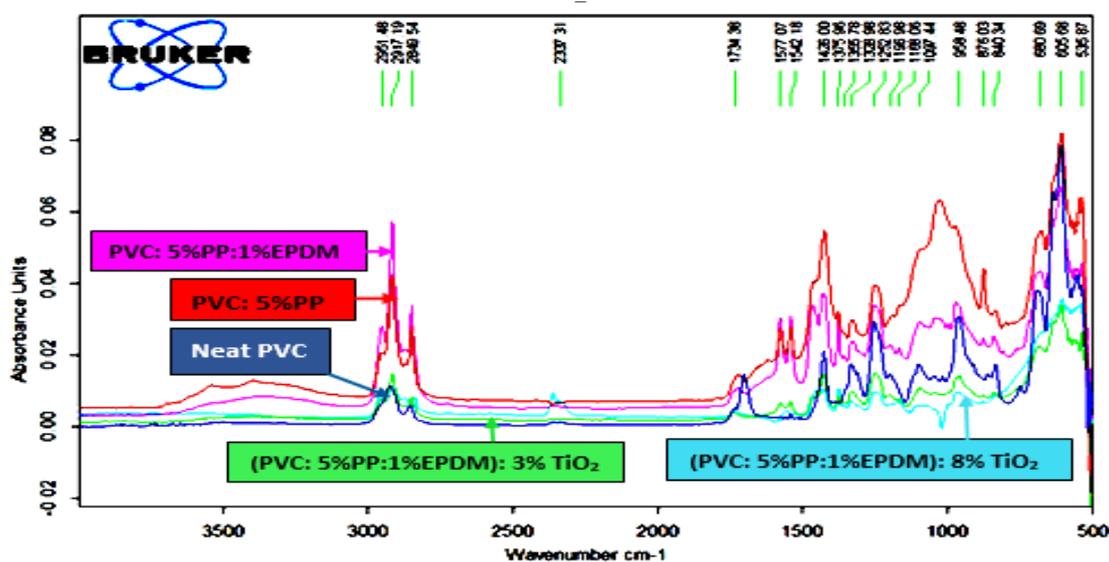


Figure 5. FTIR for ternary polymer blends (94%PVC: 5%PP: 1%EPDM) and nanocomposite [(94%PVC: 5%PP: 1%EPDM): TiO₂] as a function of (3 and 8% wt.) nano TiO₂ content.

3.2 Mechanical Properties

From the results of stress-strain curves for the compression test, of the polymer blends (PVC: X%PP), (94%PVC: X%PP: 1%ABS) and (94%PVC: X%PP: 1%EPDM), consists of different ratios of PP (5%, 10% and 15%) in the blends.

It was noticed from Figure 6 that the compressive strength for these blends decreases with increasing of PP content in the blend and this was related to the chemical structure of PP and PVC. Polyvinyl chloride and polypropylene are only different in terms of their side groups, polar chlorine versus methyl respectively. The polar side groups provide stronger intermolecular interactions that significantly affect the segmental motion of the polymer chains [25]. So, the PVC polymer displays a much higher mechanical strength as compared to the (PVC: X%PP) blends. Therefore, the addition of any polymer to PVC that has a less flexible structure like PP, will produce a polymeric blend with less flexural strength compared to the PVC alone. So, the lower values of compressive strength of polymer blends (PVC: X%PP) that is referring to the chemical structure of PP which has a methyl group on every second carbon atom of the polymer main chain producing high flexible material [25-26].

In addition, it was observed from Figure 6 that the effect of the addition of 1%ABS or 1%EPDM to the base binary polymer blend increases the compressive strength as compared to all samples of the base polymers blend (PVC: X%PP). This result related to nature of the chemical structure of ABS and EPDM, whereas the effect of adding ternary polymers such as (copolymers of acrylonitrile butadiene styrene (ABS)) or (terpolymer as copolymer made from three monomers are ethylene propylene diene monomer rubber (EPDM)) to the polymers blends (PVC: X%PP), it leads to the increase in compression strength of the samples related to the nature of these ternary polymer blends which acts as an agent to increase the interfacial reaction and provides effective compatibility between all constituent of polymer blends [27]. Further, it can be seen from Figure 6 that the polymer blend (PVC: X%PP: 1%EPDM) has the highest values as compared with polymer blend (PVC: X%PP: 1%ABS). The outcome of addition terpolymer as copolymer consisting of three monomers is ethylene propylene diene monomer rubber (EPDM) with ratio (1%wt.) to the base binary polymer blends (PVC: X%PP). That can act as good as interfacial reaction and compatibility between all constituent of polymer blend content (PVC: X%PP: 1%EPDM) compared to ternary polymer blends (PVC: X%PP: 1%ABS). Therefore, this ternary polymer blend has higher values in compression strength.

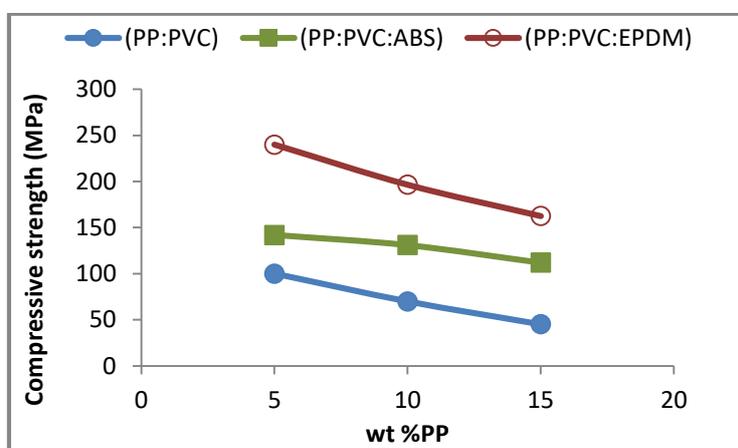


Figure 6. The compressive strength for the base polymers blend (PVC: X%PP) and Ter-polymeric blends (PVC: X%PP: 1%EPDM) and (PVC: X%PP: 1%ABS) as a function of PP content in the blend.

Figures 7, 8 and 9 show the flexible modulus, impact strength and fracture toughness respectively for the base polymers blend (PVC: X%PP) and ternary polymeric blends (PVC: X%PP: 1%EPDM) and (PVC: X%PP: 1%ABS) as a function of PP addition to the blend. From Figures 7, 8 and 9, it has been noticed that the addition of PP to the base polymer (PVC) decrease these properties, this is related to the chemical structure of PVC and PP as mentioned earlier in the section of compression results. As well as, the values of the flexible modulus, impact strength and fracture toughness properties analysed were much higher in the blends (PVC – PP) containing 1%EPDM or 1%ABS, no matter in PP concentration since the values of these properties were significantly influenced by the incorporated of EPDM or ABS to the (PVC-PP) blends, which lead to high compatibility among the constituents of polymers blend [28]. This fact demonstrates the high adhesion among the phases and a good dispersion distribution of the EPDM or ABS in ternary polymer blends and increases the mechanical properties values that were studied. According to the literature [29], good mechanical properties of polymeric blends are the result of good adhesion and compatibility among the phases immersed in the thermoplastic phase, which occurred in the present work. Moreover, it is observed that the addition of 1% EPDM gave the best values of the flexible modulus, impact strength and fracture toughness. Therefore, the polymeric blends (PVC-PP-EPDM) have higher values compared to the counterparts of polymer blend (PVC-PP-APS), and it is related to the nature of copolymer blend EPDM that is thermoplastic elastomer ternary polymer formed from ethylene, propylene and a diene, and this produced from irregular structures, which prevents from the crystallization to

take place. So, the impact strength and fracture toughness are further increased due to the low degree of crystallinity [30].

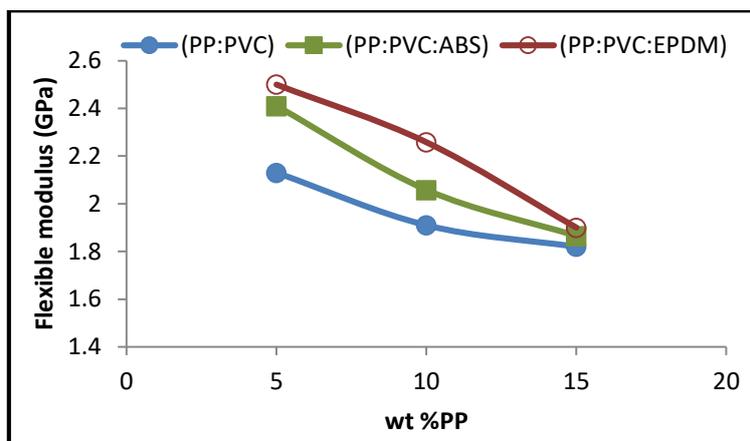


Figure 7. Flexible modulus of base polymers blend (PVC: X%PP) and ternary polymer blends (PVC: X%PP: 1%EPDM) and (PVC: X%PP: 1%ABS) as a function of PP addition to the blend.

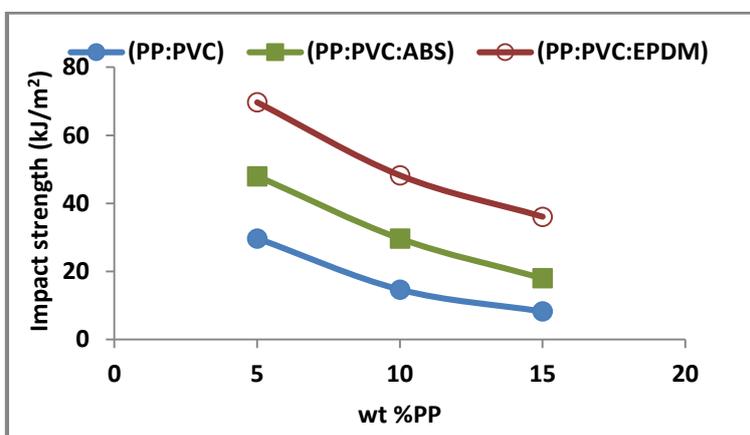


Figure 8. Impact strength for base polymers blend (PVC: X%PP) and ternary polymeric blends (PVC: X%PP: 1%EPDM) and (PVC: X%PP: 1%ABS) as a function of PP addition to the blend.

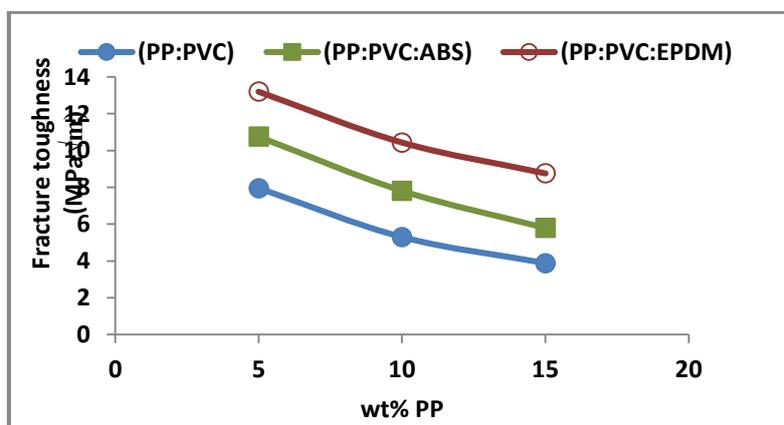


Figure 9. Fracture toughness for base polymers blend (PVC: X%PP) and ternary polymer blends (PVC: X%PP: 1%EPDM) and (PVC: X%PP: 1%ABS) as a function of PP addition to the blend.

3.3 Mechanical Test for Polymer Nano Composite Materials

According to the results of the mechanical properties for the polymers blends which are mentioned in the previous section, one sample has been selected from ternary polymers blends with ratio (94%PVC: 5%PP: 1%EPDM), which represent optimal sample in terms of mechanical properties. The sample was then reinforced with titanium dioxide nanoparticles (nano Titania (TiO_2) and the average diameter is 65.91nm) with different weight ratio (1, 3, 5 and 8%) to prepare the nanocomposites samples based on ternary polymer blend. Then, the samples are subjected to the following mechanical tests. Figures 10(a) and 10(b) show the effect of the addition of nano- TiO_2 to the polymer's blends (94%PVC: 5%PP: 1%EPDM) on the tensile strength and compressive strength respectively. Addition of TiO_2 nanoparticles increases these properties as compared with the base ternary polymer blend. These properties reach maximum values at 3% ratio of TiO_2 nanoparticles (refer Figure 10 (a) and 10(b)). It was observed that the compressive strength reaches the stable values of any increase in the nano- TiO_2 ratio higher than 3%. The increased in these properties may be related to the nature of consistency between the components of nanocomposites samples, and this refers to the good compatibility between the polymer blend components and TiO_2 nanoparticles.

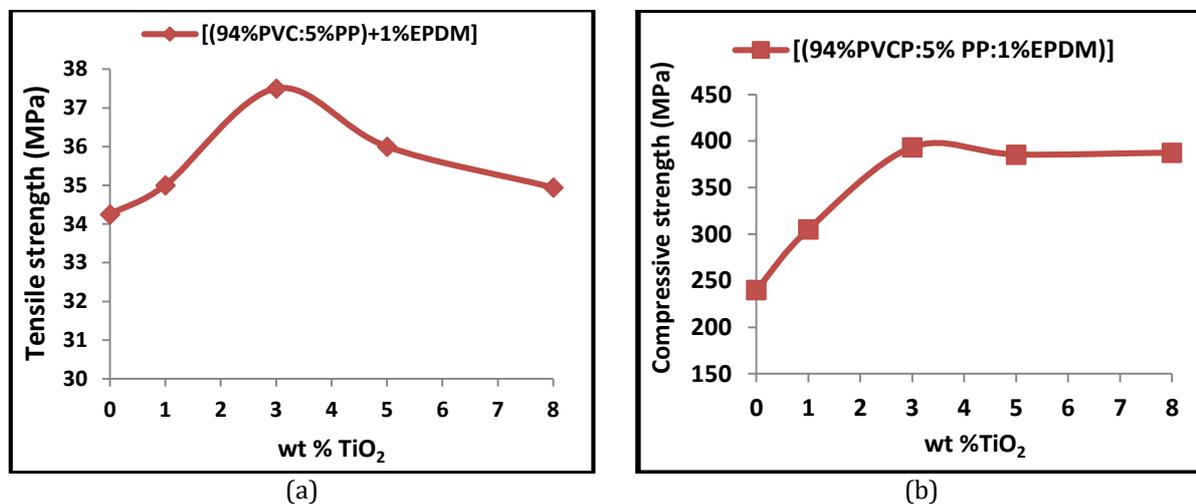


Figure 10. (a) Fracture strength, and (b) compressive strength for nanocomposite [(94%PVC: 5%PP: 1%EPDM): TiO_2] as a function of TiO_2 nanoparticles content.

The effect of adding TiO_2 nanoparticles to polymer blend (94%PVC: 5%PP: 1%EPDM) on the flexural properties (flexural strength and flexural modulus) is shown in Figure 11(a) and 11(b), respectively. It was found that the addition of TiO_2 nanoparticles increases the flexural strength and flexural modulus, where the maximum value is at 3% ratio of TiO_2 nanoparticles content in composites. Such behaviour may be due to the uniform distribution of TiO_2 nanoparticles, especially at the low ratios of nanoparticles content in nanocomposites samples, and thus reduces agglomeration of the nanoparticles especially at low concentrations and also reduce internal stresses concentration in the nanocomposite, near the clustering of nanoparticles and such small internal stresses are not enough to break the interactions at the interface regions [31]. Therefore, these small internal stresses can easily transport from the matrix material to the nanoparticles. In this case, it permits the particles to participate in its high stiffness characteristic with the polymer nanocomposites and then increase its strength [32]. This is due to the ability of these TiO_2 nanoparticles to hinder the crack propagation inside polymer blend. According to the strengthening mechanism, the strong bonding between the polymer blend matrix and particles refers to the good compatibility between the polymer blend components and nano- TiO_2 particles [33].

On the other hand, the addition of TiO₂ nanoparticles larger than 3% ratio leads to decrease the flexural strength and flexural modulus of nanocomposites as compared with base polymer blend (94%PVC: 5%PP: 1%EPDM). This could be attributed to the bad wettability and agglomeration between TiO₂ nanoparticles and constituents of polymer blend matrix, especially at high concentrations. Therefore, the resultant nanocomposite has weak physical bonding between its components, leading to a low-stress failure to occur.

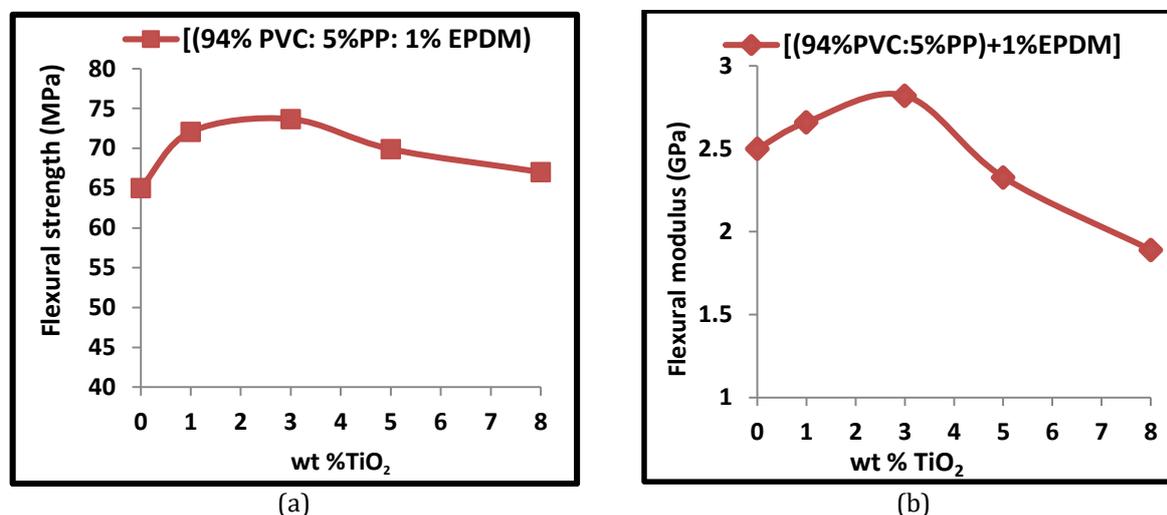


Figure 11. (a) flexural strength, and (b) flexural modulus for nanocomposite [(94%PVC: 5%PP: 1%EPDM): X%TiO₂] as a function of TiO₂ nanoparticles content.

3.4 Morphology Test (SEM Analysis)

The changes in fracture surface morphology were evaluated for the polymer blends (95%PVC: 5% PP), (95%PVC: 5%PP: 1%EPDM) and nanocomposites which were chosen as the optimum samples according to the results illustrated in the preceding paragraphs. The scanning electron microscope (SEM) photography of the fracture surface morphology of the polymer's blends (95%PVC: 5%PP) and (95%PVC: 5%PP: 1%EPDM) and polymer nanocomposite at different ratio of TiO₂ nanoparticles (3% and 8%) are shown in Figures 12 (a, b, c and d) respectively at (1000X) magnification. From microscopic imaging of fracture surface morphology (Figure 12 (a)) of the binary polymer blends (95%PVC: 5% PP) shows a heterogeneous structural morphology. In this structural morphologies, one component of the blend is represented by the substance of PP as the secondary material in the binary polymer blend dispersed in the form of particles in the medium of base polymer matrix represented by the substance of PVC. So, the binary polymer blends (95%PVC: 5% PP) exhibited heterogeneous structural morphology of matrix-dispersed phase structure, with an incompatible porous structure, which weakened the mechanical properties of binary polymer blends. There is a difference in structural morphology between the polymer blends before and after addition EPDM, addition 1%EPDM to the polymer blend (95%PVC: 5%PP) (Figure 12 (b)), which exhibited homogeneous structural morphology. There is no any new phase or phase-separated dominants in this structure free of the porous structure, that shows good interaction at the interface of ternary polymer blend constituent related to EPDM which acts as a good interfacial adhesion between polymer blend constituents [34]. On the other hand, it was observed through SEM microscopic imaging (Figure 12 (c and d)) that the morphology of the fracture surface of the polymer composites showed a co-continuous homogeneous microstructure morphology with addition TiO₂ nanoparticle in different ratios (3% and 8%). Moreover, the structures of the composite substances clarify that increasing the percentage of nanoparticles content in the composite would reduce the size of the micro structures of the prepared composites materials. Through this morphology, it was noticed that most of the nanoparticles are embedded inside the matrix material, which acts as an integral

part of microstructures of the matrix materials represented by ternary polymer blend, indicating better interfacial adhesion between constituents of composite material. This indicated a good compatibility between the constituents of polymer blend and the reinforcement nanoparticles of TiO_2 , which enhances the mechanical properties [35]. On the other side, the morphology of the fracture surface showed the occurrence of some agglomerations of TiO_2 nanoparticles, especially for high concentrations of nanoparticle content in composites, which randomly distributed within the structure of the matrix material and that can be observed, through red circles in Figure 12 (d) of nanocomposite sample which reinforced by 8% ratio of TiO_2 nanoparticles.

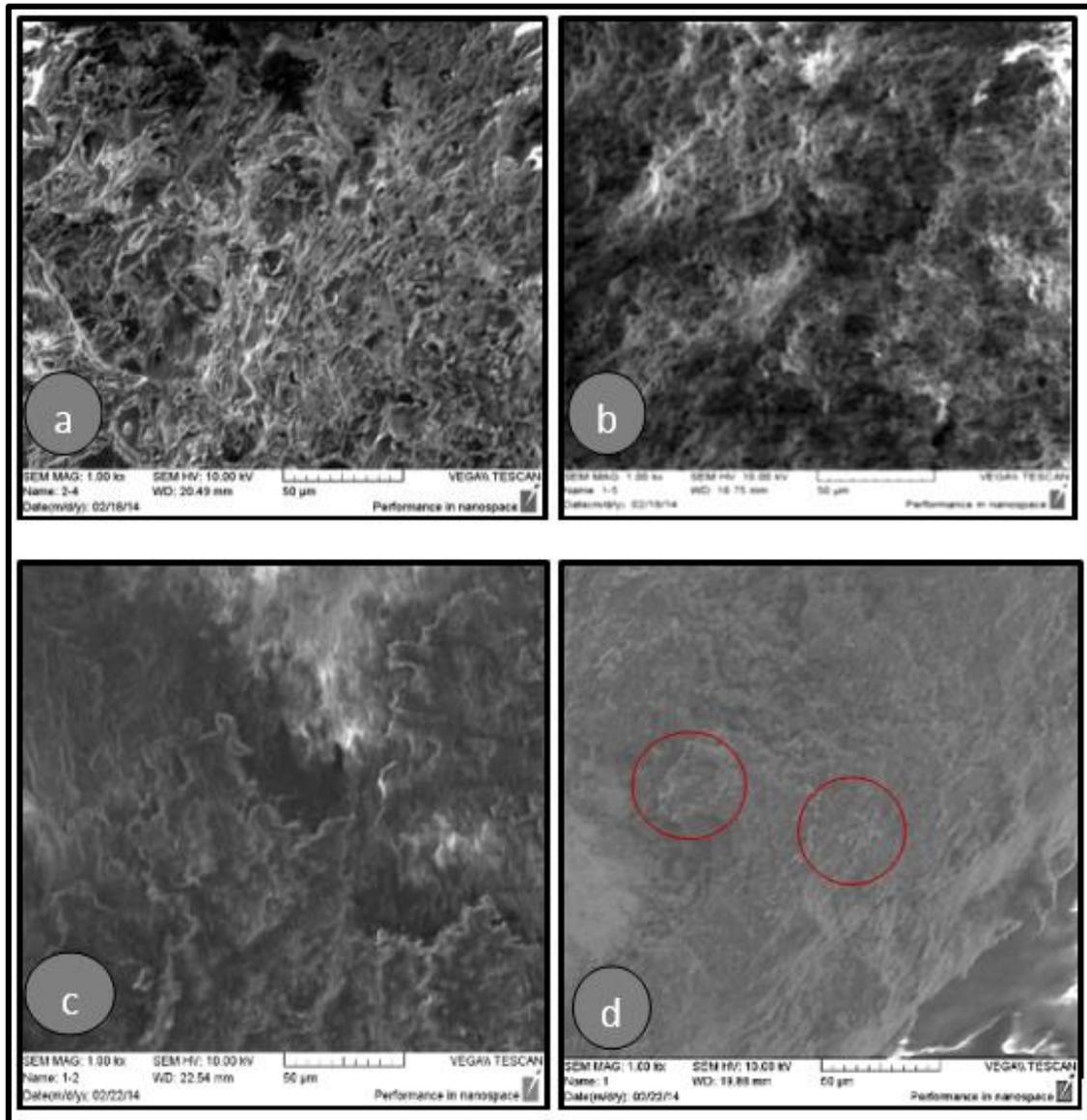


Figure 12. SEM fracture surface morphology of (a) binary polymer blend (95%PVC: 5%PP), (b) ternary polymer blend (95%PVC: 5%PP: 1% EPDM) and (c and d) nanocomposite as a function of TiO_2 nanoparticles content in the composite, where (c) 3% and (d): 8% at the magnification of (1000X).

4. CONCLUSION

The results showed that the polymer blend (PVC-PP-EPDM) achieved higher values in compressive strength, flexural modulus, impact strength and fracture toughness compared to

polymer blend (PVC-PP-ABS). This indicated that the EPDM may act as a good interfacial adhesion between polymer blend constituents and has good compatibility between the constituents of ternary polymer blends. Therefore, the ternary polymer blend (94%PVC: 5%PP: 1%EPDM) was selected as optimum polymers blends ratios before reinforcing with titanium dioxide (TiO₂) nanoparticles. The mechanical properties of the hybrid polymer nanocomposite material are enhanced with the addition of nanoparticles up to a certain level beyond a negative effect due to the formation of agglomerates that may result in poor adhesion and compatibility among the phases.

The addition of TiO₂ nanoparticles to 3% wt. to the ternary polymer blend has led to the improvement in mechanical properties of prepared composites such as the fracture strength, compressive strength, flexural strength, flexural modulus, impact strength and fracture toughness. These results indicate good compatibility between the constituents of ternary polymer blend and the reinforcement nanoparticles at 3% ratio as a result of the high efficiency for each of TiO₂ nanoparticles and EPDM in the composite. Therefore, the ternary polymer blend (94%PVC: 5%PP: 1%EPDM) and the hybrid polymer blend nanocomposites [(94%PVC: 5%PP: 1%EPDM): 3%TiO₂] which appeared to have high toughness and high strength can be foreseen to provide a valuable contribution to high-performance structural applications, especially in medical applications. Increasing TiO₂ nanoparticles to higher than 3% ratio led to the bad wettability and agglomeration between TiO₂ nanoparticles and constituents of polymer blend matrix producing nanocomposite material with weak physical bonding between its components.

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