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Preparation and Study of Flexural Strength and Impact Strength for Hybrid Composite Materials used in Structural Applications

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K E Y W O R D S

Polymer blend, PP, PMMA, flexural properties, hybrid laminar, nanocomposites

A B S T R A C T

Many of the polymeric materials used for structural purposes have weak mechanical properties, these characteristics can therefore be improved by preparing a hybrid laminar composite. In this work use melting mixing method using screw extruder to prepare sheets of polymer blends and nanocomposites based on polymer blends, and using a hot hydraulic press machine to prepared hybrid laminates composites. Two groups of hybrid laminar composites were prepared, the first group is consist of [((94%PP: 5%PMMA: 1 %(PP-g-MA)): 0.3% ZrO2): 6%KF and 8%KF] and the second group is [((94%PP: 5%UHMWPE: 1 %(PP-g-MA)): 0.3% ZrO2): 6%KF and 8%KF]. The results illustrated the impact strength and fracture toughness are increase with increased weight percentage of Kevlar fiber in for both groups of laminar composites and the highest values for two groups are (58.1, 54.95 KJ/M2) and (8.4, 9.16 MPa√m) respectively, any that, at the rate of increment reached to (120.4%, 107%) and (52.7%, 66.5%) respectively, compared with the neat PP. Moreover, the flexural strength values of the first group samples of hybrid laminar composite remained constant, when added kevlar fiber to nanocomposite. While, the flexural strength values of the second group samples of hybrid laminar composite increase with increase the ratio of kevlar fiber in composite to reach the maximum values (92 MPa) at 8% wt. of kevlar fiber, any, at the rate of increment reached to 39.4% compared with the neat PP. As well as, the results shown that the flexural properties and fracture toughness of the second group samples higher than they are for the first group samples.

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1. Introduction

In the current of technological development, most of the materials available for structural applications have come in the form of fibers (either in the form of textiles or non-woven) in small diameters (within 5 to 40 microns). The use of fibrous materials in structural applications is face many problems: negligible compressive strength of fibers due to buckling, rapid strength degradation due to the generation of surface defects by fretting and/or environmental attack, permeability, etc. [1]. These problems can be overcome by infiltrating the fiber preform with a polymeric matrix. The application of fiber-reinforced composites (FRCs), especially polymeric composites as structural materials, has grown continuously over the past 50 years due to its unique combination properties of low density, high stiffness and strength as well as toughness [2].

In addition to what mention above, there is a lot of researches work in the direction of FRC, one of them was done by A.N. Dickson et al. where this work study some mechanical properties of nylon matrix reinforced with three different types of woven fiber are (glass, carbon and Kevlar fibers). The study shows that, the mechanical properties (tensile and flexural strengths) increase with addition any type from this fiber and the highest enhancement was achieved for nylon matrix when reinforced with the carbon fiber [3].

Recently, the structural, morphological, mechanical and thermal properties have been studied of newly designed polymeric materials using high-performance hybrid fibers to reinforce the polybenzoxazine resins. Hybrid fibers consisting of chopped Kevlar and carbon fibers were subjected to surface treatment with silana, and then isothermally cured using the compression molding technique. The results shows that the values of bending strength and modulus, tensile stress and toughness reach to 237.35 MPa, 7.80GPa, 77 MPa and 0.27 MPa respectively for composite sample having 20 wt. % Kevlar fibers and 20 wt. % carbon fibers, The thermo gravimetric analysis gave an excellent thermal resistance of the reinforced hybrid composites [4]. Also, other work focuses on the hybrid polymer composite in which Kevlar and Kevlar with graphene was used as filler material in epoxy resin to enhance mechanical properties of Kevlar reinforced polymer composite. Further the performance of hybrid composite that consist of epoxy resin as a matrix with varied Kevlar dosage from 0.1 to 0.4wt% and a constant dosage of 0.3wt% of graphene has been investigated. The Kevlar reinforcement showed appreciable increase in mechanical properties [5]. Another study in the field of hybrid composites about the mechanical properties of the composites [(epoxy resin with 2% Nature rubber:5%PMMA) reinforced with (0.5%SiO2 or 3%TiO2)] were used as matrix for hybrid laminated composites materials, reinforced with different types woven fibers of(13%E-glass fibers or 13%Kevlar fibers). the results showed that the mechanical properties (tensile strength, flexural strength, impact strength and fracture toughness) increase with addition any type of woven fiber and also the results shows the polymer blend nanocomposite [(EP: 2%NR: 5%PMMA):0.5%SiO2] reinforced with any type fiber (woven glass fiber or woven kevlar fiber) giver higher mechanical properties as a compared with [(EP: 2%NR: 5%PMMA):3%TiO2] reinforced with same type and ratios of fiber [6]. In one of structural applications of polymer composite materials consisting of (PMMA- (nano hydroxyapatite or micro zirconia) - woven fiber (glass fiber or kevlar fiber)) the results shown enhancement in compressive strength values with added (nHA and ZrO2) and the maximum of compressive strength reached for PMMA when reinforced with (ZrO2 powder and glass fiber) [7].

The current work is an attempt to improve some important mechanical properties in the direction of structural applications for polypropylene material , through the preparation of hybrid laminar nanocomposites by addition one or two layers of woven kevlar fiber, to the plates prepared from nanocomposites based on polymer blends of (PP: 5% PMMA: 1%(PP-g-MA)) and (PP: 5% UHMWPE: 1%(PP-g-MA)).

2.Materials and Methods

I. Materials

Materials used in this work are polypropylene (PP) in a pellet form grade (500P), provided from Sabic Company. PMMA material supplied from china (Xlamen Keyuan Plastic co., Ltd.) have density (1.18- 1.19 Kg/m^3) and melt flow rate (2-3 g/10min). Ultra-high molecular weight polyethylene (UHMWPE) was supplied from china in a pellet form have specific gravity (0.9 g/m^3) and melt flow rate (2 g/10min). (Polypropylene-grafted-maleic anhydride (PP-g-MA)) provided from china in a powder form with melt temperature is 150 °C and zirconia nanoparticle provided from china with particle size (56.45nm). Atomic force microscopy (AFM) was used to measure average particle size of ZrO_2 nanoparticles, Figure 1 shows the particles size distribution and three-dimensional (XYZ) AFM image for zirconia nanoparticle. Kevlar fiber (49) supplied from (E.I.Dupont de. Nomours Company), as form a woven mat with fibers angle direction (0° /90°), it has a yellow color.

II. Procedure Part

The polymer blends were prepared with selected weight ratios according to the formula (94%PP: 5% PMMA: 1% (PP-g-MA)). The samples of polymeric nanocomposites were prepared with selected weight ratios according to the formula shown in Table 1. The forming process was carried out using a single screw extruder. Table 1 shows extrusion parameters and composition of samples.

For optimum distribution all components of composite which are the polymers in pellet form and zirconia nanoparticle were mixed together in dry condition at room temperature for 40 minutes by a sealed mill made of porcelain material. Forming process was carried out using a single screw extruder with a screw L/D of 30:1. Each set of polymer blend and nano composite materials were melted in screw extruder machine with an extrusion speed and with the extrusion temperatures according to the three zones of extrude (feed zone, compression zone and melting zone) aforementioned in Table 1 the melted polymer pellets pass through a mold at the ending of the screw to produce sheet with dimensions (200mm x 10mm x 2mm).

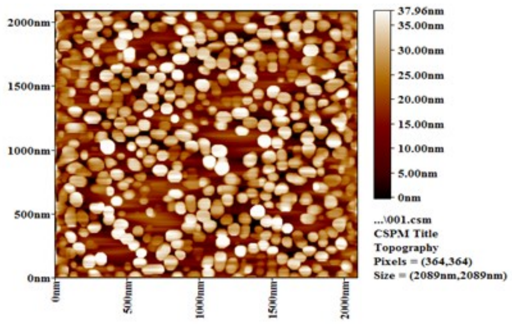
To prepare the hybrid laminates composites samples, was done by added one or two layers of the woven kevlar fiber between sheets of hybrid laminates composite sequentially, Table 2 shows the weight percentage of constituents of hybrid laminates composites samples, where Kevlar fiber is added in a continuous layer along nanocomposite sheet. After that these sheets (nanocomposites+ layers of woven kevlar fiber) put in suitable mold and put inside hot hydraulic press machine for (10 minute) under pressure (5 bar) and temperature (190°C) to bind nano-composites sheets with Kevlar layers. Then the prepared plat of hybrid laminates composites was cut according to international standard specifications ASTM for each test.

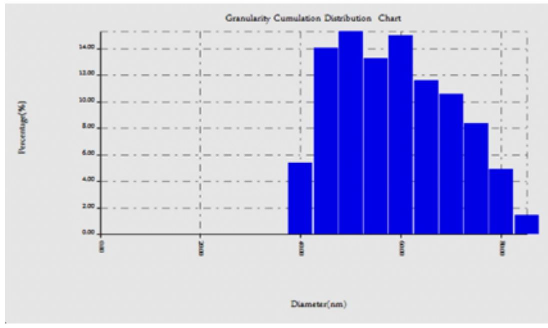
Table 1: Extrusion parameters and composition of samples.

Nanocomposites based on Polymer blends	**Temperature (ºC)**			**Screw speed (rpm)**
	Zone1	**Zone 2**	**Zone 3**	
Neat PP	190	200	210	45
(94%PP: 5% PMMA: 1% (PP-g-MA))	195	205	210	45
(94%PP: 5% UHMWPE: 1% (PP-g-MA))	190	200	210	45
[(94%PP: 5% PMMA: 1% (PP-g-MA)): 0.3%ZrO_2]	195	205	210	20
[(94%PP: 5% UHMWPE: 1% (PP-g-MA)): 0.3%ZrO_2]	195	205	210	20

Table 2: Weight percentage of the hybrid laminates composites.

Hybrid laminates composites	
Group One	[(94% PP: 5%PMMA: 1% (PP-g- MA)): 0.3%ZrO_2]: 6% Kevlar fiber
	[(94% PP: 5%PMMA: 1% (PP-g- MA)): 0.3%ZrO_2]: 8% Kevlar fiber
Group Two	[(94% PP: 5%UHMWPE: 1% (PP-g- MA)): 0.3%ZrO_2]: 6% Kevlar fiber
	[(94% PP: 5%UHMWPE: 1% (PP-g- MA)): 0.3%ZrO_2]: 8% Kevlar fiber





(a) Three-dimensional (XYZ) AFM pictures
Avg. Diameter: 56.45 nm
<=50% Diameter: 55.00 nm

(b) granularity accumulation distribution chart
<=10% Diameter: 40.00 nm
<=90% Diameter: 70.00 nm

Figure 1: Atomic Force Microscopy of the zirconia nanoparticles where (a): granularity accumulation distribution chart of zirconia powder and (b): Three-dimensional (XYZ) AFM pictures for zirconia powder.

III. Physical and Mechanical tests

The (FTIR) test was done according to the (ASTM E-1252) standard [8], by a test machine type (TENSOR-27). Infrared spectrum was used within range of (400- 4000) $cm^{-1.}$ Flexural test was done by using a three-point method according ASTM D790 standard [9]; by a test machine, model (WDW 200 E), this test was carried out with speed of cross-head 2mm/min. Impact test was enforced at room temperature according to (ISO-179) [10], by Impact test machine, model (XJU). All tests were carried out at a room temperature (23 ± 5 °C) and atmospheric pressure.

3. Results and Discussions

I. FTIR Spectrum test results

This test is used for fully characterization of FTIR spectra for neat polypropylene, polymer blends (PP: 5% PMMA: 1% (PP-g-MA)) as control sample and its nano-composites specimens and hybrid nanocomposite. The spectra of nano-composites based on polymer blend (PP: 5% PMMA: 1% (PP-g-MA)) which was reinforced with 0.3% ratio of ZrO_2 and hybrid nanocomposite [((PP:5%PMMA:1%(PP-g-MA)):0.3%ZrO_2):8%K F] were shown in Figure 2. From this figures it was observed that, all the characteristics vibration bands of polymers blends (94% PP: 5% PMMA: 1% (PP-g-MA)) and its nano-composites is quite similar to that reported by [11 and 12] for polypropylene, where the band observed at (2949.74 and 2867.58 cm-^{1}) confirms the presence of C-H_2 asymmetric stretching and symmetric stretching band respectively. The peak at 1454.64 cm^{-1}confirms the presence of asymmetric in plane CH_3 bending and the peak at 1166.56 cm^{-1} attributed to CH_3 wagging and peaks at 890.75, 840.43 cm^{-1} are attributed to CH_3 rocking, CH_2 rocking and C-C stretching respectively this result are in a good agreement with previously reported in literature [12 and 13].

Figure 3 shows the FTIR spectra of polymer blends (PP:5%UHMWPE:1%(PP-g-MA)), nano-composites based on polymer blend (PP: 1% (PP-g-MA): 5% UHMWPE) which was reinforced with 0.3% ratio of ZrO_2 and hybrid nanocomposite [((PP:5%UHMWPE:1%(PP-g-MA)):0.3%ZrO_2) :8%KF], From this figures it was observed that, all the characteristics vibration bands of polymers blends (94% PP: 5% UHMWPE: 1% (PP-g-MA)) and its nano-composites is quite similar to that mentioned earlier and reported by [11 and 12], where the band observed at (2949.74 and 2837cm-^{1}) confirms the presence of C-H_2 asymmetric stretching and symmetric stretching band respectively. The peak at 1454.64 cm^{-1}confirms the presence of asymmetric in plane CH_3 bending and the peak at 1166.56 cm^{-1} attributed to CH_3 wagging and peaks at 886.79, 852.13 cm^{-1} are attributed to CH_3 rocking, CH_2 rocking and C-C stretching respectively [14]. As well as, from these infrared spectra Figures 2 and 3, it was observed there is no shifting in peaks of characteristic frequencies of nano-composites, relative to those spectra of polymer blend. This indicates to occurrence of physical bonding and absence from any chemical reactions or cross linking that may be occur as a result of the blending process between all components of the nanocomposite materials [15].

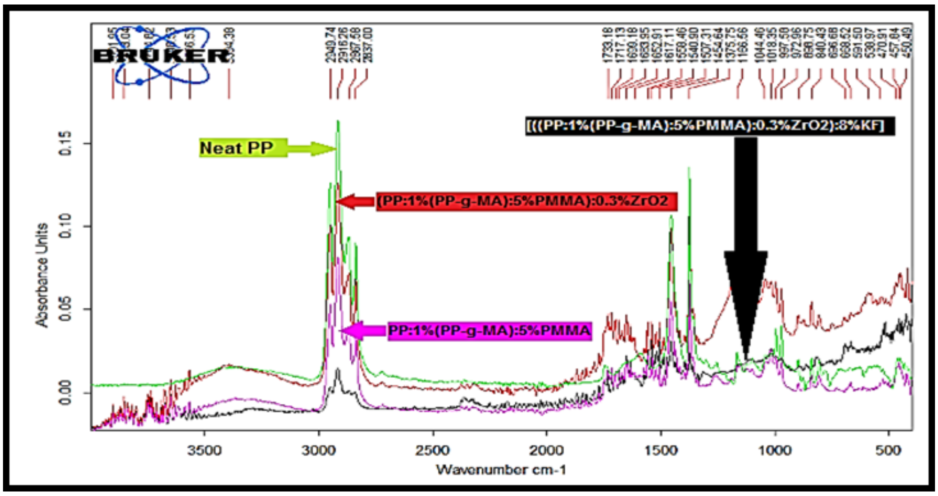


Figure 2: FTIR spectra of polymeric blends (PP: 5% PMMA:1% (PP-g-MA)), nanocomposite ((PP: 5%PMMA:1%(PP-g-MA)): 0.3%ZrO_2) and hybrid nano composite [((PP: 5%PMMA:1%(PP-g-MA)): 0.3%ZrO_2): 8%KF].

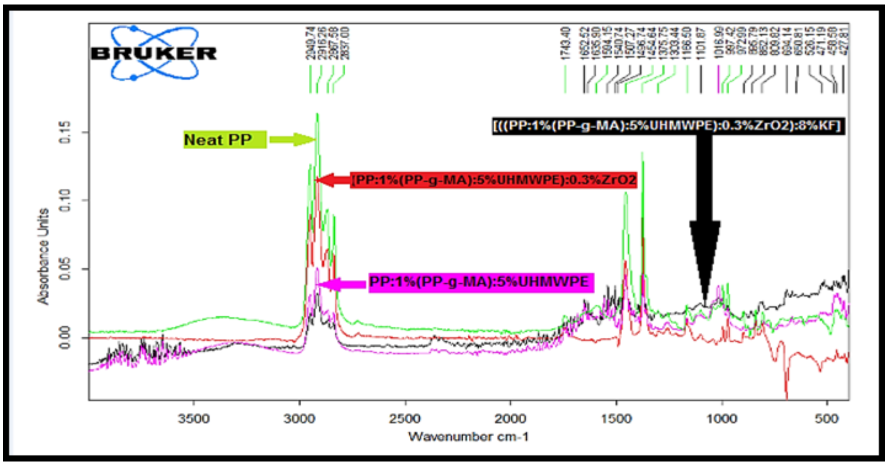


Figure 3: FTIR spectra of polymeric blends (PP:5%UHMWPE:1% (PP-g-MA)), nanocomposite ((PP:5%UHMWPE:1%(PP-g-MA)):0.3%ZrO_2) and hybrid nanocomposite [((PP:5%UHMWPE:1%(PP-g-MA)):0.3%ZrO_2):8%KF].

II. Mechanical tests results

Flexural properties (flexural strength and flexural modulus) and impact properties (impact strength and fracture toughness) that was carried out on neat PP, polymer blends ((PP: 5%UHMWPE: 1% (PP-g-MA)) and (PP: 5%PMMA: 1% (PP-g-MA)), nanocomposite materials and hybrid laminated composites materials are shown in Figures 4 and 5 respectively. It was noticed from these figures that the flexural properties (flexural strength and flexural modulus) increased when addition any each one of polymer blends (X%UHMWPE-1% (PP-g-MA)) or (X%PMMA-1% (PP-g-MA)) to the neat PP, where was adding (1% (PP-g-MA) as compatibilizer material to increase compatibility between polymer blend. As well as the results showed the flexural properties of polymer blend which contain on (PP: 5% PMMA: 1% (PP-g-MA)) have highest values as compared with the polymer blend contain on (PP:5%UHMWPE:1% (PP-g-MA)). These results are related to the different in the polymeric chains structures of PP, PMMA and UHMWPE materials, where the chemical structure of PMMA chains which contain on two sides groups (CH_3 and $COOCH_3$) on every second carbon atom of repeat units for the main carbon chain which gave major hindrance of the movement of chains and thus makes polymer blends relatively strong [16]. Also, can be noticed from these figures the values of flexural properties increased when addition 0.3% ratio of ZrO_2 nanoparticles to both types of polymer blends (PP: 5%PMMA:1%(PP-g-MA)) and (PP:5%UHMWPE: 1%(PP-g-MA)). This is due to the strengthening mechanism and nature of bonding, at interface between reinforcing material and polymer blend matrix. As well as, this increase may be due to the fact of high flexural properties of the ZrO_2 particles as compared with components of the polymer blend matrix [17]. Moreover, it can be noticed from Figure 4, that the values of flexural strength increase with addition of woven kevlar fiber for both types of laminated hybrids composite specimens, this is related to high mechanical properties of Kevlar fiber as compared to matrix material and due to good bonding strength between interfacial of matrix material components and kevlar fiber. Furthermore, it was observed that the hybrid laminated composite [((PP:5%UHMWPE:1 %(PP-g-MA)):0.3%ZrO_2):%KF] have higher flexural strength compared to hybrid laminated composite which contains on PMMA instead of UHMWPE [((PP:5%PMMA: 1%(PP-g-MA)):0.3% ZrO_2):%KF], this is may be attributed to good wettability of kevlar fiber by matrix material which contain on the UHMWPE material have high flexibility compared to the PMMA material, this lead to good adhesion between fiber and components of nanocomposites that contain on UHMWPE thus obtaining better mechanical properties. Where the flexural strength values of the second group samples of hybrid laminar composite increase with increase the ratio of kevlar fiber in composite to reach the maximum values (92 MPa) at 8 %wt. of kevlar fiber, any, at the rate of increment reached to 39.4% compared with the neat PP. On the other hand, from Figure 5, it was noticed when adding Kevlar fibers to composite material, led to decreased the flexural modulus values for both types composites and this property decrease with increases proportion content of Kevlar fibers in composites, this result associated with nature of woven kevlar fiber that have flexural modulus lower than that of composite matrix material [18].

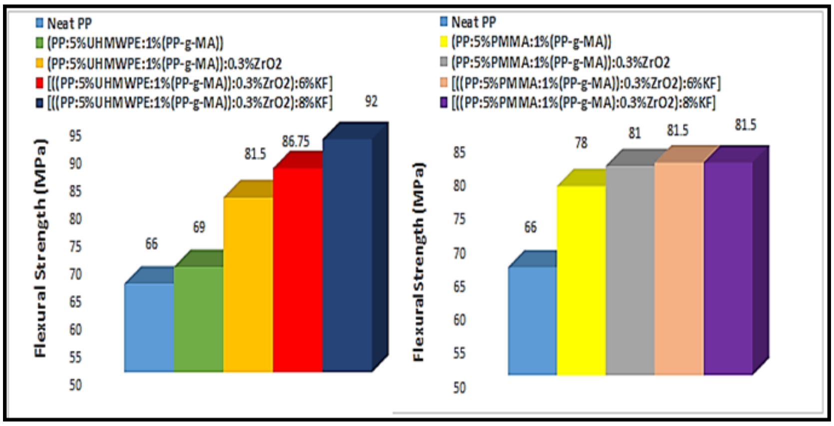


Figure 4: Comparison of flexural strength values between neat PP material and two types of polymeric blends, nanocomposites based on polymer blend and hybrid nano composites [((PP:5%UHMWPE:1%(PP-g-MA)):0.3%ZrO_2): 6% or 8%KF] and [((PP: 5%PMMA:1%(PP-g-MA)):0.3%ZrO_2): 6% or 8%KF].

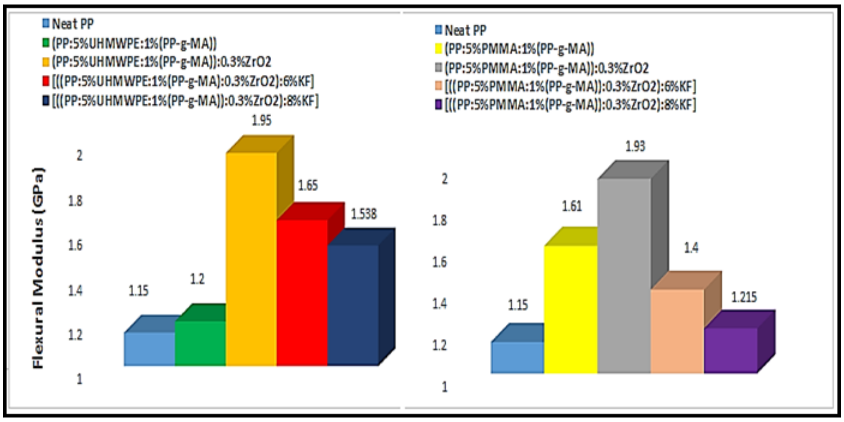


Figure 5: Comparison of flexural modulus values between neat PP material and two types of polymeric blends, nanocomposites based on polymer blend and hybrid nano composites [((PP: 5%UHMWPE: 1% (PP-g-MA)) 0.3%ZrO_2): 6% or 8%KF] and [((PP: 5%PMMA: 1% (PP-g-MA)):0.3%ZrO_2): 6% or 8%KF].

Figures 6 and 7 show the comparison in impact strength and fracture toughness values respectively for the neat PP, ternary polymer blends, nanocomposite based to the same polymer blend and for both types of hybrid laminated composites.

These figures show that the addition of (5% UHMWPE) or (5%PMMA) with (1%(PP-g-MA) to the neat PP lead to increase the impact properties, where the results indicated, that the polymer blend sample which contain on (5%UHMWPE) possess higher impact strength and fracture toughness values, where the values as shown in Figures 6 and 7 increased from (26.36 KJ/M^2 and 5.5 MPa√m) for the neat PP to ((41.33 KJ/M^2 and 7.04 MPa√m) for polymer blend (PP: 5%UHMWPE:1%(PP-g-MA)) respectively, any that, at the rate of increment reached to (56.8%, 28%) respectively, compared with the neat PP. whereas, the values of impact strength and fracture toughness for the blend sample (PP: 5% PMMA: 1% (PP-g-MA)) which contain on PMMA material instead of UHMWPE material, reached to (28.46 KJ/M^2 and 6.75 MPa√m) respectively, this result related to molecular chains structure of the PMMA and the natural of chains structure of Ultra-high-molecular-weight polyethylene (UHMWPE) is a linear polyethylene has an extremely high molecular weight that has characteristics high energy absorption and extremely high impact resistance [19]. Moreover, from these Figures can be noticed, that the values of impact properties slightly increase when added 0.3% ratio of ZrO_2 nanoparticles to both types of polymer blend, but when adding of woven Kevlar fiber to nanocomposites (which based on polymer blends as matrix material), impact strength and fracture strength increased compared to the values of nanocomposites samples. Where the values increased from (42 KJ/M^2 and 7.69MPa√m) for nanocomposite ((PP:5%UHMWPE:1%(PP-g-MA)):0.3%ZrO_2) to the values (54.59 KJ/M^2 and 9.16 MPa√m) for hybrid nanocomposite samples [((PP:5% UHMWPE:1% (PP-g-MA)):0.3% ZrO_2): 8%KF] respectively, any that, at the rate of increment reached to (120.4%, 107%) respectively, compared with the neat PP. whereas the values of these properties reached to (58.1 KJ/M^2 and 8.4 MPa√m) for hybrid nanocomposite samples [((PP: 5% PMMA: 1% (PP-g-MA)):0.3% ZrO_2):8%KF] which contain on PMMA material instead of UHMWPE material any that, at the rate of increment reached to (52.7%, 66.5%) respectively, compared with the neat PP these results are in a good agreement with other reported [15]. This results could be attributed to the fact that Kevlar fibers are characterized by higher impact strength than nanocomposites samples, as well as, as previously mentioned this is may be attributed to good wettability of kevlar fiber with matrix material this lead to good interfacial bonding between kevlar fiber and components of hybrid nanocomposites samples, thus lead to obtaining better mechanical properties. Therefore, that lead to improving the impact properties of the hybrid laminated composite specimens [18].

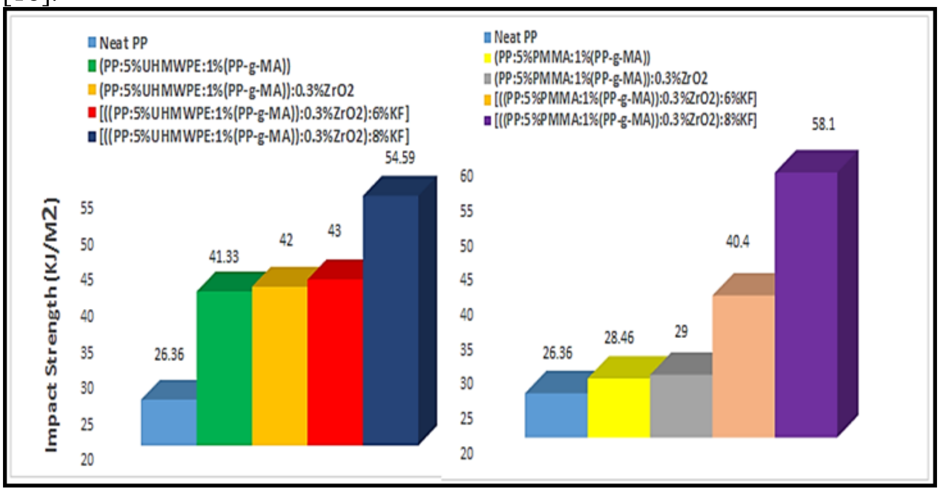


Figure 6: Comparison of impact strength values between neat PP material and two types of polymeric blends, nanocomposites (based on polymer blend) and hybrid nano composites [((PP:5%UHMWPE:1%(PP-g-MA)):0.3%ZrO_2): 6% or 8%KF] and [((PP: 5%PMMA: 1%(PP-g-MA)): 0.3%ZrO_2): 6% or 8%KF].

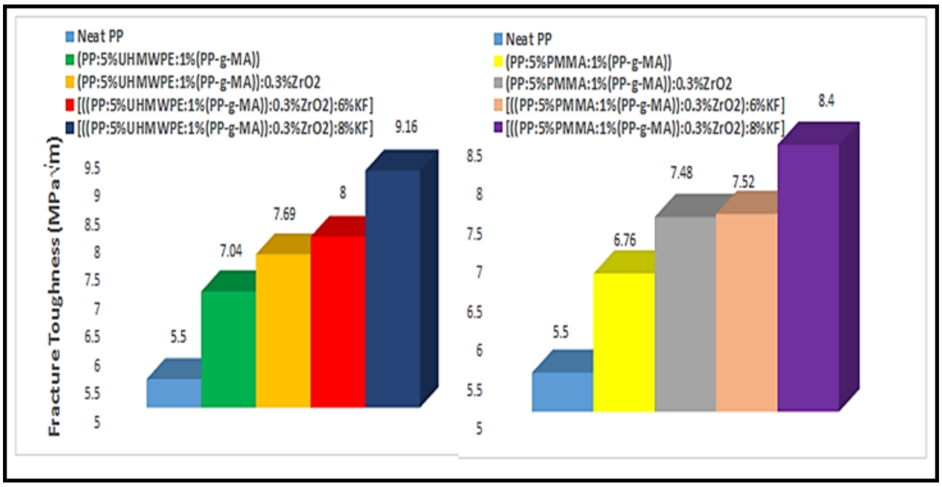


Figure 7: Comparison of fracture toughness values between neat PP material and two types of polymeric blends, nanocomposites (based on polymer blend) and hybrid nano composites [((PP: 5%UHMWPE:1%(PP-g-MA)):0.3%ZrO_2): 6% or 8%KF] and [((PP:5%PMMA:1%(PP-g-MA)):0.3%ZrO_2): 6% or 8%KF].

4. Conclusion

1- Based on the results of the current work, it is possible to conclude that the hybrid nanocomposites prepared are promising materials for use in structural applications, especially those requiring high durability.
2- Addition 5%wt. of PMMA or UHMWPE to PP increased the properties of flexural strength, flexural modulus, impact strength and fracture toughness.
3- The addition of 0.3% wt. of ZrO_2 nanoparticles to the ternary polymer blends has a noticeable effect on mechanical properties especially that for the flexural properties (flexural strength and flexural modulus).
4- The mechanical properties (flexural strength, impact strength and fracture toughness) increased with addition woven kevlar fiber to nanocomposites (have a matrix of polymer blends), while there was a decrease in the values of the flexural modulus.
5- FTIR test results indicates to occurrence of physical bonding and absence from any chemical reactions between the components of the polymer blends, nanocomposites and the hybrid laminate nanocomposites as compared to neat PP.

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