Recent Advances in Ternary Blends of Nanocomposite and Their Impact on the Mechanical and Thermal Properties: A Review

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Abstract. The numerous studies were performed on the polymer blends and their nano-composite, the sub-inclusion of nano-particles in the binary polymer blend modifies thermal and mechanical properties of the system. At the other hand, very few literatures are available in view of the ternary blends of polymers with addition of nano-particles. The ternary polymer blends with their rheological and morphological properties are reviewed in this research work. The specific work is concentrated on PP (polypropylene)-PS (polystyrene)-PMMA (Poly (methyl methacrylate)) ternary blends with or without compatibilizer in presence of the MWNT (Multiwall carbon nanotube) nano-particles and improvement in mechanical and thermal properties of the resulting material were studied. In the literature, Impact of the mixing time and dispersed phase content were observed in relation with volume average diameter and volume percentage. Addition of SEBS (Styrene-ethylene-butylene-styrene) to the PP/PS blend decreases stress at breaking point and increases impact strength. SIS (Polystyrene-block-polyisoprene-block-polystyrene), LUC (maleic anhydride Lucofin R 1492M HG) and PODIC ((Peroxan C126), a dimyristylperoxydicarbonate)) are excellent compatibilizers for enhancing impact Strength.

Keywords: Nanocomposite · polymer blend · compatibilizers · DTG

1 Introduction

Composites are characterized with superb mechanical properties over an extended span of temperatures. Copper as a base material in composite are reinforced with carbon fibers as an application in the electrical and electronic industry are characterized by high heat conductance and useful properties with great wear resistance [1]. Ceramic Composites are best for Thermal Heat exchangers and to enhance mechanical properties of material in static loads [2]. Polymer Composite generally consists of polymer as matrix and other linear or nonlinear reinforcement/fillers. This reinforcement improves strength of polymer composite without changing other relevant properties of polymer [3]. Automobile, Aerospace, Construction, Medical and Sport Industries uses wide verity

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of polymer composite. Some time, the required properties can't be achieved by single polymer matrix-reinforcement set. There are several applications where properties like tensile strength, impact strength, toughness and material life have equal importance in the planned composite. Such exclusive material can be prepared by combination of multiple polymers with multiple reinforcement materials [4].

2 Polymer, Nanomaterial and Their Impact on Properties

Recent research shows wide application of binary blends in automobile and biomedical industries. More variation in properties can be achieved by polymer ternary blends and inclusion of different fillers [5]. Application of nanomaterial in polymer blends enhances mechanical properties of the composite [6]. The polymer blends can be reinforced by either organic or inorganic materials and polymer may be thermoset or thermoplastic [7]. Blends of thermoplastic are more focused than the thermoset because of the feasibility towards industrial application. Nanomaterials are generally classified as nanoclay, nanotubes, nanofibers and nanoparticles. All of these are proved to enhance verity of mechanical properties including toughness, tensile and flexural strength [8]. At the other hand nanodiamonds as a filler material in elastomer-polymer blend increases elasticity as well as strength but decreases wear resistance [9].

3 Blend Proportions and Property Relation

In general, most of times the polymer blends are supposed to be immiscible in nature. They need compatibilizer to improve blend quality in order to achieve optimization in interfacial tension, stability in morphology under high stresses and increase adhesion in solid phases [10]. Multiple compatibilizer are available to improve toughness, impact strength, tensile strength, melt flow and other relevant properties. For PP (polypropylene)-PS (polystyrene) blend 90:10 shows good ductility, blend homogeneity. But if blend ratio modified to 75:25, it retains ductility and enhances impact strength [11]. For immiscible polymer blends, the properties on which study concentrate, are dependent of drop structure the compatibilizer plays important role in increase of viscosity [12]. As shown in Fig. 1, SiO_2 with treatment by POTS vapour deposited on the

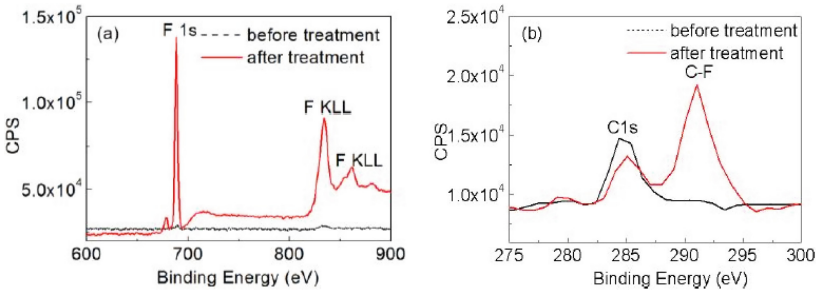

Fig. 1. XPS graph: Nanoparticles of SiO_2 with and without treatment by monolayers of POTS (perfluorooctyltriethoxysilane) under X-ray photoelectron spectroscopy for (a) F and (b) C-F [13].

surface introduces super-hydrophobicity, also nanomaterials are used as filler material, and exclusively they can be used for surface coating, Silica as nanomaterial can be used as Super-hydrophobic surface coatings [13]. Nanomaterial inclusion in polymer blend has crucial impact on the tensile strength and modulus of elasticity [14]. The composites can be prepared by multiple processes like hand-lay process, bag moulding process, pultrusion, filament winding, resin transfer moulding and injection moulding. Among all types, the injection moulding process provides uniform and qualitative polymer blend concentration [15].

4 Nanomaterial Inclusion

Not only the process but orientation of particle structure is having equal importance that manipulates the polymer blend properties. Nanotubes may be arranged parallel to loading axis for quality improvement of mechanical properties [16]. Considering microscopy observations of MWNT (Multiwall carbon nanotube) filled PP/PMMA composite i.e., SEM (Scanning Electron Microscope), Electrical measurements and TEM (Transmission Electron Microscope) confirmed that it has a dual percolated phase [17] that MWNT are particularly situated at the boundaryof two phases in the PMMA-PP (70:30) blends. The electrical infiltration of dual percolated form is 0.48 wt%. The inclusion of MWNTs, the morphology of polymer nano-composite gets modified. As per Fig. 2, final outcome of the PMMA- HDPE-PS (Poly(methyl methacrylate) -High Density Polyethylene- Polystyrene) polymer blend shows that the capsulation process occurs with short-time in the formulation process and retains in constant time period. The resulting morphology is consisting with the matrix material of HDPE, a PS spread morphology, and inclusion of the PMMA polymer inside the PS phase [18].

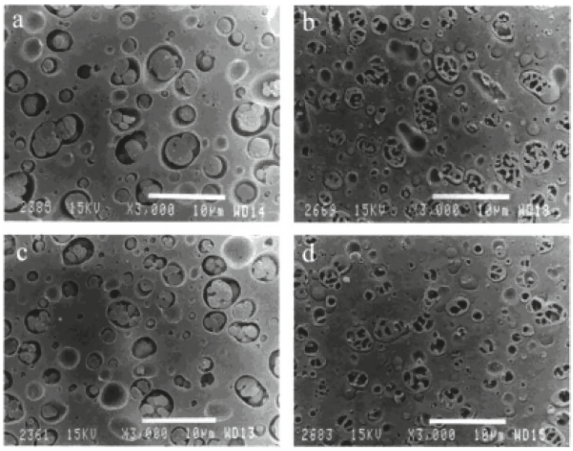

Fig. 2. SEM (Scanning Electron Microscope) photo-micrographs for Impact of mixing time on phase dispersion. HDPE (70)-PS (15)-PMMA (15) blend at 10 [μm] after PS phase extraction (first column) and the sub-inclusion of PMMA (second column) [18]

5 Analysis of Ternary Blends

As shown in Fig. 3 and 4, For the blend of PP-PS-PMMA, the characteristics influencing the positioning of MWNTs and its effect on morphology generation of PP-PS-PMMA compositions that have thermodynamically favorable core and shell morphology [19]. The MWNTs concentration as well as morphological characteristics of composite observed with method of viscoelastic experiments (melt linear) together with electron beam microscopic results. In another research, composites of poly (methyl methacryate), polyethylene and polypropylene were studied [20]. Using clay of the styrene-contain allows mixing of the clay with polypropylene, instead of the standard requirement for maleation, for production of composites. The structures are characterized with the aid of XRD (X-ray diffraction), TEM, Analytical thermogravimetry, calorimetric cone along with the observation of mechanical characteristics. These novel clays open few possibilities for clay and polymer melt mixing to acquire composites with vital characteristics. The addition of organ clay to notably immiscible blends of PS and PP blends results in a essential alteration in blend rheology and morphology [21].

Figure 5 shows TGA and DTG curves, the grafted monomer (EGMP) ethylene glycol methacrylate phosphate polymerized by alumina particles have been completed with a purpose to achieve a higher fire retardancy and thermal stability to nanocomposites of PS and PMMA [22]. Polymerization and grafting techniques are being investigated the usage of TGA (Thermogravimetric Analysis), FTIR (Fourier transform infrared spectroscopy) and elemental analyses.

The PS-PMMA blend mixed with nanomaterial may be taken into consideration a really good component for specially environmental, clinical and business packages inclusive of: biosensors, lens, antibacterial, transistors, electronics gates and many others. During such evaluation, the observation of polymer structure, blend, composite substances and composites of nanomaterial have been studied [23]. In case of PS-PMMA

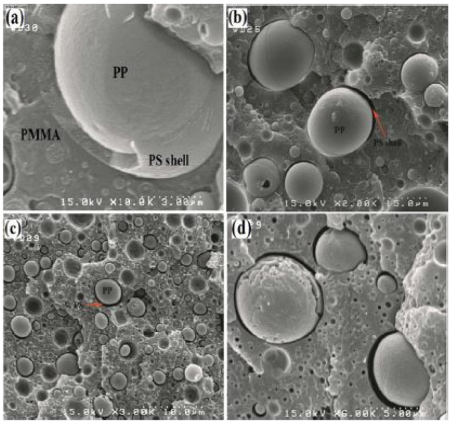

Fig. 3. SEM micrograph of the fractured surface on the field emission scanning electron microscope of (a) PMMA (80)-PS (15)-PP (15), (b) PMMA (80)-PS (05)-PP (15) composition where the cyclohexane etching was applied to the PS phase for time period of 8 h, (c) for time period of 24 h, (d) image of PMMA (80)-PS (10)-PP (10) ternary blend [19]

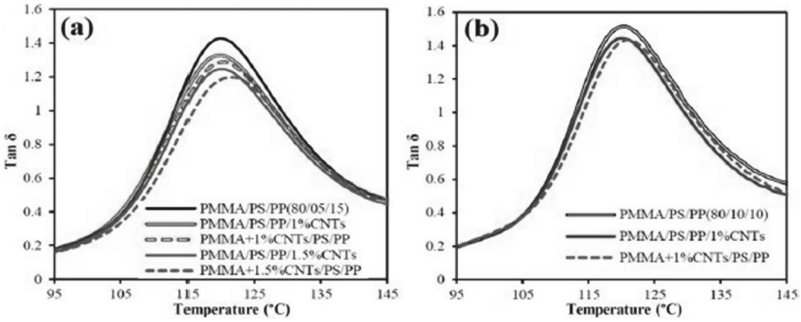

Fig. 4. DMA (Dynamic Mechanical Analysis) graphs of the ternary polymer combinations with and without MWCNTs were created by the simultaneous feeding mode and sequential feeding mode: (a) PMMA (80)-PP (15)-PS (05) and (b) PMMA (10)-PS (10)-PP (10). [19]

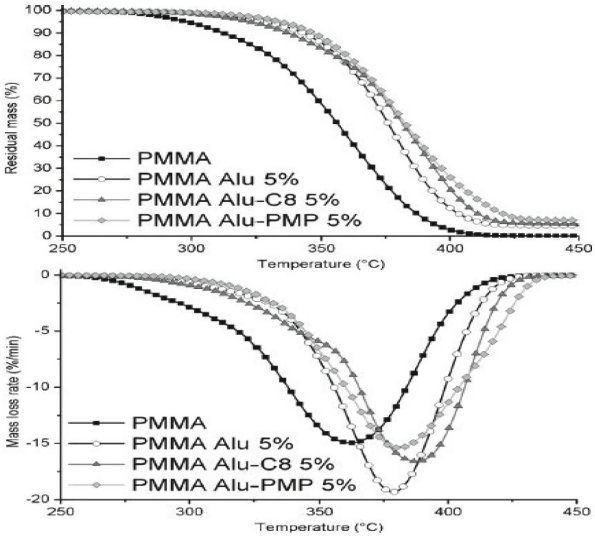

Fig. 5. TGA (Thermo gravity Analysis) and DTG (Derivative Thermogravimetry) graphs for PMMA nanocomposite with varying alumina and other nanomaterial concentration [22]

blend, for PS with individual unequal molecular weight, and PP-PMMA mixture combination ranged within 10 to 35% of the obtained phase (PP or PS) [24]. The information was observed to study the interfacial tension probability between the blend polymers from the rheological properties. For nanoparticles added composites, a reduction in the size of droplet upon inclusion of nanoparticles resulted into the compatibilisation process [25]. The spread and position of nanoparticle was then observed as it is an important factor in study of compatibility system. The outcomes on separate polymers

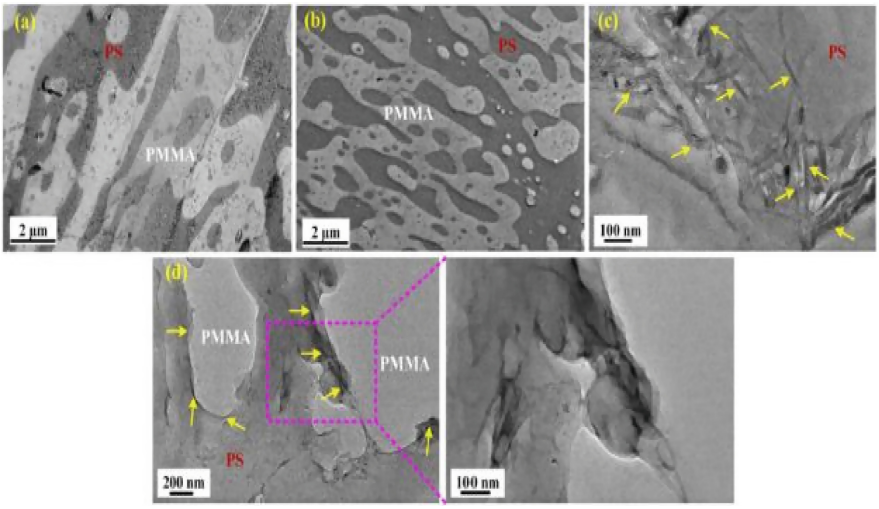

Fig. 6. TEM Micrographs for (a) MS, (b) W-MS, (c) MS-GO (0.8), and (d) MS-W-GO (0.8) nanocomposites [28]

proved, the nanoparticle was mixed properly in the PMMA as compared with polymer of the PS. The films of PMMA-PS blend of two unequal sizes studied by (AFM) atomic force microscopy and (XPS) X-ray photo-electron spectroscopy. Blends were spin cast with various combinations on the mica as interdependent solvent with chloroform. X-ray photo-electron spectroscopy readings showed surface improvement in all compositions for PMMA material. The layer which is thicker that provides a good quality of PMMA surface improvement. Atomic force microscopy allows contrast in the blends with varying combinations [26].

Generally pitted surfaces observed for the blend of PMMA bulk concentration with less than 50%; the varying size occurs for different layer thickness and majority combination. The surface modifies to the separated phases structures, as combination is greater than 50%, for the PMMA. Then In PMMA/PS blend, a dependable and off-on approach of morphology detection the use of light microscopy is established. The approach gives rapid statistics that will be applied to differentiate among special categories of morphological behavior. The electrons microscopic images are modeled for property prediction purposes image characteristics are included and examined [27].The features combination permits category of multiple morphologies of PS-PMMA compositions. The rheological characteristics of blends permit additionally discrimination among exceptional morphologies. Figure 6 shows TEM micrographs, The PS-PMMA-GO with 40–60% mixture nano polymer composites exhibits excellent constant form. The overall impact of the force of screw shear force and water injection provides higher homogeneity and excellent exfoliation of the graphene surfaces within the PS form and assists their transport to the phase association [28]. The Graphene surfaces on the boundary can engage with the PMMA-PS phases to generate the pie-pie assembly and bond of the hydrogen, consecutively, as a result enhancing the non-mixing PMMA and PS

phases compatibilization. Increasing Graphene content improves the compatibilization effect. For, the viscoelastic characteristic and structure of PP-PMMA polymer blends to which a piece of copolymer PP-g-PMMA, the concentration of polymer varied up to 10 by wt. % in relation with the homogeneous structure phase concentration. The interfacial tension studied by the rheological. For PP-PMMA composition as a compatibilizer PP-g-PMMA is effective one [29].

As modifier PP-g-PMMA added with the specific mixture of the interface saturation, multiple rheological characteristics were developed at the blend mixture: for 90-10 concentration, the storage modulus decreased and for 70-30 concentration, the storage modulus, increased as compared to the unmodified blend at lower frequencies; In case of 90-10 concentration, the interfacial relaxation time with respect to the compatibilizer was offered by the relaxation spectrum. The best composition of the interface saturation, as compared to the unmodified concentration the storage modulus of all composition was improved [30]. Straight blends and their composition with nanoparticle show droplet morphology under. PMMA-MAPP combination shown the continuous phase after inclusion of C15A, indicating increase in interfacial mixing within the MAPP and PMMA morphology. A unique melting peak of PP-PMMA composition and its nano polymer blends were observed in DSC results, at the other and for MAPP-PMMA composition double melting peaks were observed. Inclusion of PP, PMMA and LDPE increases the impact properties for nanocomposite system. The PMMA decreases elongation characteristics but PP or LDPE works better in elongation [31]. The non-crystalline polymer may be present as liquid at temperatures beyond its glass transition temperature, from a thermodynamic point of view. In other perspective, by rheology it is not liquid up to the point where, temperature is increased far above its glass transition point [32] (Table 1).

6 Results and Discussion

PP-PS-PMMA ternary polymer blend with graphene nanoparticles is practically achievable nanocomposite. Compatibilizers like SEBS, SIS, LUC, PODIC are used for proper blending of PP-PS based ternary polymer blends. Silica nanoparticles deposited with POTS grafting by chemical vapour deposition on the test material works excellently for achieving super-hydrophobic nature on the surface of polymer blends. Inclusion of nanodiamonds in the elastomer based polymer blend enhances elasticity and strength. Polymer blends are capable of getting reinforced by both organic and inorganic materials. PP-PS (90:10) results in good ductility and modifying blend proportion to (75:25) introduces impact strength in the polymer composite. EGMP and Alumina nano particles are useful for improving fire retardancy and thermal stability to polymer nanocomposite of PS and PMMA blend. PP-g-PMMA is effective compatibiliser for proper mixing of the PP-PMMA polymer blend. Ternary PMMA-PP-PS polymers creates core-shell morphology for variation of PS from 5% to 15%, Overall mechanical and thermal properties of polymer blends can be modified by changing variation of blend composition, inclusion of nanoparticles, addition of compatibiliser and modifiers.

Table 1. Effect of compatibilizer on the mechanical and thermal properties of polymer blends

Sr.No.	Polymer	Modifying Material	Property Enhancement	
			Mechanical	Thermal
1	PP + PS (100/0)	N/A	BPS = 24.9 [Mpa]	GT = 25.6(PP)
			EB = 24.5%	
			IS = 2.7 [kJ/m^2]	
2	PP + PS (80/20)	SEBS 5%	BPS = 23.5 [Mpa]	GT = 29.5(PP), 117.0 (PS)
			EB = 22.3%	
			IS = 2.8 [kJ/m^2]	
3	PP + PS(50 + 50)	SEBS 7%	BPS = [27.2Mpa]	GT = 25.7(PP), 115.7 (PS)
			EB = 4.3%	
			IS = 2.4 [kJ/m^2]	
4	PP + PS (0/100)	N/A	BPS = 33.2 [Mpa]	GT = 112.1 (PS)
			EB = 2.7%	
			IS = 1.9 [kJ/m^2]	
5	PP + PS (90/10)	N/A	BPS = 34.6 [Mpa]	–
			IS = 2.6 [kJ/m^2]	
6	PP + PS (90/10)	SIS 3%	BPS = 32.4 [Mpa]	–
			IS = 3.6 [kJ/m^2]	
7	PP + PS (90/10)	LUC 3%	BPS = 31.5 [Mpa]	–
			IS = 4.3 [kJ/m^2]	
8	PP + PS (90/10)	PODIC 1%	BPS = 34.5 [Mpa]	–
			IS = 3.5 [kJ/m^2]	
9	PP + PS (70/30)	N/A	TS = 43.5 [Mpa]	GT = 121.4
			FS = 45.8 [Mpa]	
			IS = 1.76 [kJ/m^2]	
10	PP + PS (50 + 50)	N/A	TS = 38.2 [Mpa]	GT = 121.0
			FS = 42.7 [Mpa]	
			IS = 1.88 [kJ/m^2]	

Note: PP: Polypropelene, PS: Polystyrene, SEBS: Styrene-ethylene-butylene-styrene, SIS: Polystyrene-block-polyisoprene-block-polystyrene with an MFR of 3.0 g/10 min (200 °C/5 kg) and a bound styrene content of 22 wt.%, LUC: maleic anhydride Lucofin R 1492M HG, PODIC: (Peroxan C126), a dimyristylperoxydicarbonate (10 h half-life time at 48 °C), BPS: Breaking point Stress, EB: Elongation at Break, IS: Impact Strength, GT: Glass Transition Temperature in oC, TS: Tensile Strength, FS: Flexural Strength.

7 Conclusions

The review of literature provides sufficient information about material behavior under varying wt. %. The polymer blend can be prepared with hybrid fillers and tested for different mechanical, morphological and thermal properties. Ternary blends from polymers of different properties can be mixed together and exclusive material with tailored properties will be achieved. The PP/PS/PMMA ternary polymer blend with inclusion of nanofillers like MWNT and graphene is unique composition and has great potential as new research topic. Also, with this distinctive set mechanical, morphological and thermal properties and co-relation among them can be studied. Inclusion of nanofillers and blending proportion can be summarized and composite with tailored properties can be recommended for development of potential application in automotive interior trim.

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