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A STUDY OF NANOCOMPOSITES OF POLYMER BLENDS FOR INVESTIGATED OF ELECTROMAGNETIC-PROTECTIVE SHIELDING MATERIALS

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ABSTRACT

In present study, poly(3,4-ethylene dioxythiophene)/reduced graphene oxide nanocomposites were prepared for EMI shielding applications in the microwave range. The present work includes the synthesis of PEDOT/RGO nanocomposites via in-situ emulsion polymerization method. The as-synthesized PEDOT/RGO nanocomposites were incorporated with dielectric and magnetic fillers material with a view to investigate their effect on electromagnetic wave absorbing property. Blending of polymers is an attractive and inexpensive method for getting low cost and novel structural materials. Polymer composites are polymer based matrix with materials embedded in the matrix, as reinforcements. The reinforcement materials include carbon black, carbon fibers, graphite, carbon nanotubes, calcium carbonate, metal oxides, silica, talc, montmorillonite, etc. The reinforcement improves the physical and chemical properties of the polymer composites. Polymer nanocomposites are a new class of structural materials of which distinct components are dispersed on a scale of nanometers which improves the mechanical, thermal, electrical, optical, magnetic, barrier and flame retardant properties without significant loss of physical and chemical properties. Electromagnetic interference shielding (EMI) is becoming more prominent these days due to the development of newer devices which produce, receive and process electromagnetic radiation. The demand for high performance EMI shielding materials is continuously increased for protecting or shielding the device from the interference from any other devices or objects. One of the promising materials for the EMI shielding is conductive polymer nanocomposites. The EMI Shielding Effectiveness (SE) depends on many factors like the dispersion of nanofillers, shape, electrical conductivity and dielectric property of the nanocomposites. The electrical conductivity of insulating polymers filled with conductive fillers suddenly increases at some critical concentration of the conductive fillers. The fillers can be metallic particles, carbon black, carbon nanotube etc. The conductive filler forms a network that facilitates the flow of electricity through the composite. Through the blending of polymers the percolation threshold could be reduced. Thus, it is expected that a heterogeneous polymer blend with conductive fillers shows a higher EMI shielding effectiveness due to their higher conductivity.

KEYWORDS: Polymer Composite, Blend Nanocomposites, Electromagnetic Shielding Protective, polymerization method, PEDOT/RGO nanocomposites

INTRODUCTION

In recent years, many efforts have been carried out by microwave engineers, scientists, and technologists to develop EMI shielding materials using conducting polymer nanocomposites. Conductive polymer composites have been identified as the promising materials for EMI shielding applications as they can eliminate the disadvantages of conventional metal-based EMI shields owing to their light weight, versatile nature, low cost and good processability. Recently, carbon nanotube has attracted as reinforcement for polymer blend nanocomposites, due its high electrical conductivity, mechanical property and high aspect ratio. Through the blending of polymers, the percolation threshold value can be lowered than the nanofillers with individual polymers. The compatibilisation of the polymer blend will reduce the interfacial tension, enhance the interfacial adhesion and enhance the dispersion of the fillers in the matrix, and stabilise the morphology of the blend. This study is an attempt to develop high EMI shielding materials of MWCNT based polymer blend nanocomposites with low percolation threshold. The reinforcement action of MWCNT improves viscoelastic, thermal, electric and dielectric properties of polymer blend nanocomposites. The high electrical conductivity and EMI shielding effectiveness of the fabricated blend nanocomposite opens a new platform for the development of high performance materials for EMI shielding applications.

POLYMER BLENDS

The demand of high performance polymers has changed the focus of current research in the polymer technology to the development of new polymer blends. Through the blending of costly polymer with cheaper polymer can be develop the new functional polymeric materials with existing processes. The polymer blending is a simple method of combining two or more different advantages properties in a single system. However, it is not always successful due to the incompatibility between polymers. Polymer blend is a mixture of two/more polymers with/without any chemical bonding between the polymers. Different polymers are blended essentially to provide economic advantages. Melt blending of polymers is an immensely attractive and inexpensive method of getting the novel and different structural polymeric materials. We can attain a good cost/ performance ratio by the mixing of low-cost polymers with expensive polymers. They can be miscible or immiscible. The miscibility of polymer blend depends on the thermodynamics of mixing. Most of the blend systems are immiscible due to unfavorable interactions and very low contribution of entropy. The properties of the blend composite depend upon the miscibility between the polymer structure and selection of the component polymers. It does not mean that immiscible blends have little use in industries. The immiscibility allows preserving the good properties of each of the polymer components of the blend. For example, the impact strength of a polymer can be improved significantly by adding an elastomer. The challenge is to develop processes or methods that allow to control the morphology and interfaces of phase-separated blends. This processes or techniques are called compatibilisation. The entropy of mixing is very low due to their high molecular weight. For thermodynamic miscibility, homogeneity, the free energy of mixing should be negative. This condition is attained when the specific interactions are exiting between polymer components. The various materials advantage accomplished by blending of polymers is:

- Development of new structural polymeric materials with low cost.
- Ease of processability.
- Production of materials with improved properties like extended service temperature range, increased toughening, improved modulus and hardness.
- Improved barrier property and flame retardant property.

Through the blending, new materials are developed with/without little sacrifices in properties. The properties of polymer blends are determined mainly by the miscibility of the components and phase morphology.

CLASSIFICATION OF POLYMER BLENDS

Polymer blends can be divided in to three based on the miscibility between component polymers.

Completely miscible

Polymer blend that is a single-phase structure over certain ranges of temperature, pressure, and composition. The miscibility of two polymers is depending on the definite interactions between polymer molecules. For miscible blend the Gibbs free energy of mixing should be negative. However, for polymer systems, the change in entropy is negligible. Therefore the Gibbs free energy of mixing can only be negative if the enthalpy of mixing is negative. This means that mixing should be exothermic. Therefore, miscible blend requires a specific interaction between the constituent polymers. These interactions including hydrogen bonding, ion-dipole, dipole-dipole, and donor-acceptor interactions. Examples of miscible blends are PET/PBT, PMMA/PVDF, etc.

Partially miscible

For partially miscible blends, some of the blend component is dissolved with another component of the blend. The partially miscible blend has a fine phase morphology and acceptable properties. Both blend phases are homogeneous, and have their own Tg. Both Tgs are shifted from the values for the pure blend components towards the Tg of the blend component.

Immiscible

Immiscible polymer blends show a completely phase separated morphology. Immiscible blends have different Tgs corresponding to the Tg of the component polymers. Examples of immiscible blends are PA/ABS, PA/PPO, PC/PP, etc. Immiscible blends have poor physical properties, sharp interface and weak interfacial adhesion between the blend phases. The immiscible blends have become commercially successful after being efficiently compatibilized using right compatibiliser. A wide range of phase morphologies could be obtained by varying the composition ratio and viscosity of component polymers. The immiscible blends show disperses drops to fiber to lamella to co-continuous structures (Figure 1).

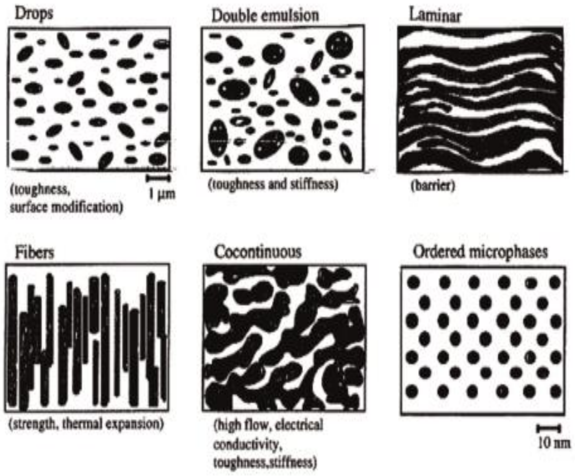

Figure 1 Phase morphologies of polymer blend systems

Among these, the co-continuous structure is particularly interesting to the fabrication of conductive composites. The disperse droplets morphology can be improved impact strength, tensile strength and toughness of the composites. The laminar like morphology can be used for barriers for solvents. Controlling the morphologies is critical to final performance of the blend.

The size of the dispersed droplets can be expressed in terms of Critical Weber number.

$$W_e = G\,\eta_m a_n/\gamma \qquad (3.1)$$

Where we is the Weber number, G is the shear force applied, ηm is the matrix viscosity, an is the diameter of the dispersed phase and γ is the interfacial tension. From Equation 3.1, it is clear that the size of droplets is depends on the matrix and minor component melt viscosity.

THERMODYNAMIC RELATIONSHIP OF POLYMER BLEND

Polymer blend is a mixture of two or more polymers with/without any chemical interaction between them. Most of the polymer blends are immiscible as given by the laws of thermodynamics. The miscibility of polymer blends depends on the value of Gibbs free energy of mixing ΔGm. The free energy of mixing is given by:

$$\Delta G_m = \Delta H_m - T\Delta S_m \qquad (1)$$

where, ΔG_m is the free energy of mixing per unit volume, ΔH_m is the enthalpy of the mixing and ΔS_m is the entropy of the mixing. In high molecular weight solution, the enthalpy of mixing is a deciding factor for miscibility. The entropy for long chain macromolecules is generally low and so entropic contribution cannot overcome contribution from enthalpy of mixing ie, the free energy of mixing should be negative. For miscibility the following conditions should be satisfied:

i. ΔG_m should be a negative value i.e,

$$\Delta G_m < 0 \qquad (2)$$

ii. The following Inequality must be satisfied

$$\left[\frac{\partial^2 \Delta Gm}{\partial \Phi_i^2}\right]_{T,P} > 0 \qquad (2)$$

Where φi is the volume fraction of component. ΔGm for a binary mixture can vary with composition. (Figure 2)

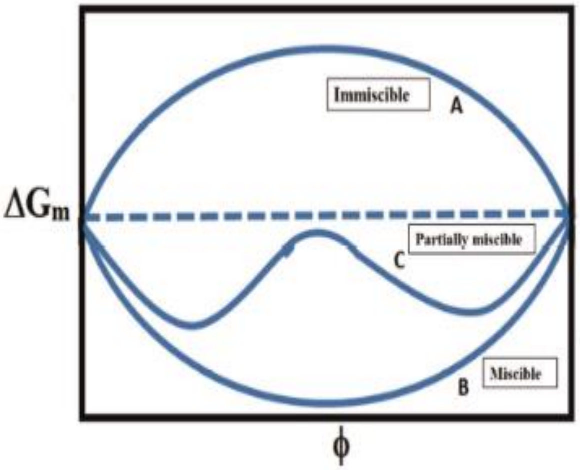

Figure 2 Gibbs free energy of mixing of binary blends

In immiscible polymer blends, Gibbs free energy of mixing is positive. Blends described by curve A violate Equation. (1) and are completely immiscible. The above criteria are met by curve B for all compositions In miscible polymer blends, molecular level mixing of the components is obtained and is characterized by single phase morphology (curve B). A system described by curve C is partially miscible, in which a single amorphous phase can be formed at compositions to the left and right of the minima of curve C. Immiscible blends do not satisfy the conditions proposed in Equation. 3 and 4 and show a two-phase morphology. In the case of partially miscible blends, the second criterion is not satisfied and will show either two phase or single-phase morphology.

COMPATIBILISATION OF IMMISCIBLE POLYMER BLENDS

Compatibilisation of immiscible blends, a method that alters and controls the morphology and interfaces of immiscible blends. The properties of polymer blends depend on the morphology and the interphase properties. Immiscible polymer blends have very low interfacial adhesion between component polymers and unstable morphology. The compatibilisation process improves the performance of an immiscible polymer blend by adjusting the interfacial tension, stabilisation of the morphology and enhances adhesion between the phases. Basically, there are three different approaches for compatibilising immiscible polymers:

1. Non-reactive compatibilisation: adding non-reactive block or graft copolymers;
2. Specific compatibilisation: attaching to polymer chains groups having non-bonding specific interactions;
3. Reactive compatibilisation: introducing reactive molecules capable of forming the desired copolymers in-situ, directly during blending. The other compatibilisation method is the addition of nanofillers into the polymer blends.

NON-REACTIVE COMPATIBILISATION

Non-reactive compatibilisation is the conventional method to compatibilising immiscible polymer blends. When added to an immiscible polymer blend, a well-selected copolymer bearing two separate segments, usually a block or a graft copolymer will be situated preferentially at the interfaces of the polymer components. Each segment will interact to the phase with which it has a specific affinity. This will be reducing the interfacial tension, improve the interfacial adhesion, help dispersion of the dispersed phase in the matrix, and stabilise the morphology of the blend. Suitable block and graft copolymers can be used as compatibilisers for polymer blends. There are many kinds of graft copolymers useful in blend systems as compatibilisers. A well-known method for polyolefins is to graft maleic anhydride onto polyolefins. Polypropylene grafted maleic anhydride (PP-gMA) has been established as an effective compatibiliser for blending PP with polar polymers, which the PP part of the PP-g-MA is compatible with PP, and the anhydride part reacts with the polar component of the polymer. Akbari et al. used PP-g-MA as a compatibiliser in polypropylene (PP)/polyethylene terephthalate (PET) blend composite. Morphological results show that the grafted PP promotes fine dispersed phase morphology in blend system (Figure 3). Ploypetchara et al. prepared PP/PLA blend films compatibilised with PP-g-MA by melt mixing technique and film extrusion. Zhu et al. used PP grafted with maleic anhydride(PP-g-MA) as a compatibiliser in the PET/PP blend system. Zhihui et al. studied the effects of the compatibiliser polypropylene grafted with glycidyl methacrylate (PP-g-GMA) on the morphology and mechanical properties of PC/PP blends. Krištofič and Ujhelyiova studied the PP-g-MAH as a comprising agent in the polypropylene/ polyamide blend. Tol et al. fabricated co-continues PS/PA6 blend compatibilized using the reactive styrene-maleic anhydride copolymer with 2 wt% maleic anhydride. They have investigated the effect of compatibilisation on the phase inversion and the stability of the resulting co-continuous blend structures.

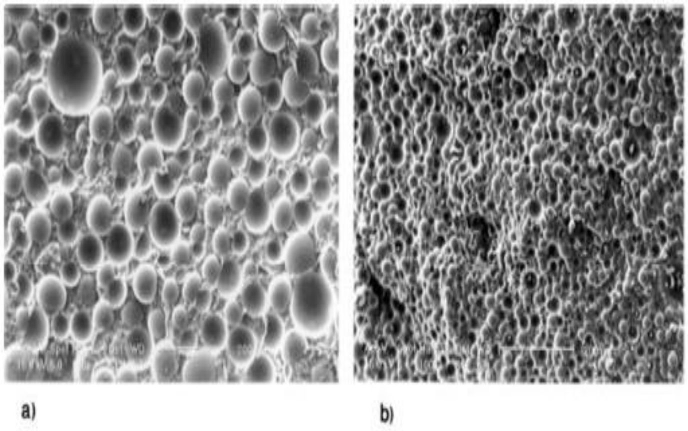

Figure 3 SEM micrographs of PP/PET blends, (a) without compatibiliser; (b) with 5 wt % compatibiliser

Compatibilisation effect of nanofillers

Compatibilisation of immiscible polymer blend using copolymers, graft polymers have little advantage to the strength and stiffness of polymer blends. However, their addition even weakens the mechanical properties. Moreover, copolymers with definite structure are often not easily synthesized, which makes them relatively expensive. Therefore, looking for another potential compatibilisation strategy at low cost is highly required. Recently, a new approach has been introduced: compatibilisation by addition of nanofillers. In the past several years, a large number of research papers have been reported on fillers as compatibiliser for polymer blends. The compatibilisation role of nanofillers in polymer blends depends on thermodynamic, wettability, dynamic processes and nature of the nanofillers. In 2002 Utracki state that nanoparticles can act as compatibiliser, if they confirm a strong interfacial adhesion between two incompatible polymers. The nanofillers are to be selectively localised either in one phase or at the interface. The nanofillers located at the interface, reduces the coalescence of the dispersed phase and stabilise the blend morphology by reducing the interfacial tension. If the fillers are dispersed in one phase, the viscosity ratio of polymer component is changed, which can affect the morphology of the blend. Vo and Giannelis compatibilized Poly(vinylidene fluoride)/Nylon-6 blends using nanoclay. The degree of compatibilisation brought by the nanoclay is dependent on the localisation of the particles and the degree of clay dispersion. Cao et al. developed an effective method for compatibilising PA/PPO immiscible polymer blends by incorporating graphene oxide sheets (GOS). The diameter of the dispersed phase (PPO) is significantly reduced, indicating improved compatibility in the GOS filled polymer blends (Figure 4). Li et al. reported the compatibilisation effect of TiO2 nanoparticles in the PET/PP blends. Al-Saleh studied the compatibilisation effect of MWCNT in polypropylene/polyethylene blends.

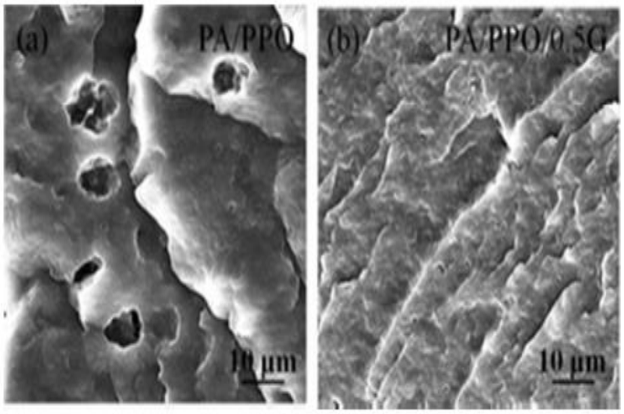

Figure 4 SEM micrographs for the cryogenically fractured surfaces of uncompatibilised and GOS-compatibilized PA/PPO blends after THF etching

POLYMER NANOCOMPOSITES

An introduction to polymer nanocomposites

Polymer nanocomposites a new form of structural materials of which distinct components is dispersed on a scale of nanometres. The mechanical, thermal, electrical, optical, magnetic, barrier and flame retardant properties are improved without significant loss of physical and chemical properties. The fillers such as nanotubes, clay, metal/metal oxides nanoparticles are used to improve the properties. Only a few per cent (0.15%) of the filler is required to improve the properties. These systems require controlled mixing/compounding, stabilisation of the achieved dispersion, and orientation of the dispersed phase. Almost all types of polymers, such as thermoplastics, thermosets and elastomers have been used to make polymer nanocomposites. Nowadays polymer nanocomposites are commonly used in aerospace, sports goods, automobiles, industrial equipment etc. The reinforcement materials include glass fibers, carbon materials (carbon black, fibers, graphite, nanotubes), calcium carbonate, metal oxides, silica, talc, montmorillonite etc.

Role of fillers in polymer nanocomposites

The usage of fillers for the improvement of polymer properties has been extensively studied. Initially the fillers were particularly used to reinforce the mechanical properties of the polymer. Traditional fillers particles in the micro-meter range such as talc, glass fibers, carbon black, calcium carbonate, etc. But, most micron sized fillers require high loading for property enhancement. This makes difficulty in processing due to the high viscosity of the filled materials. Moreover, the high density of micro sized fillers also leads to heavier composites. The interfacial interaction between the filler and the polymeric matrix is very low. In the past few decades, many research studies have been carried out to study the reinforcement effect of nanofillers in the polymer composites. Nanofillers in the range of 3%–5% by weight attain the same reinforcement as 20%–30% of micro-sized fillers. Nanofiller materials have emerged as an attractive candidate as fillers as their increased specific interfacial area assists higher interfacial interactions between filler and polymer matrix. Nowadays carbonaceous nanofillers such as nanotubes and graphene attracted due to the excellent properties such as high mechanical strength and high aspect ratio. The blending of polymers leads to only some marginal enhancement in properties which are still insufficient for engineering applications. The method for improvement in the compatibility between the polymer pairs has attracted significant attention in industry and academia. An effective way to improve their physical properties is by introducing the nanofillers into the polymer blend such as carbon nanotube, graphene clay, silica nanoparticles and etc. In recent years, nanoparticles have attracted a lot of interest due to their important role in immiscible and incompatible polymer blends. In the immiscible polymer blend, the fillers improve both the physical properties and the compatibility between the polymers. Fillers such as carbon nanothube, nanosilica, nanoclay, graphene and etc. are promising candidates for the modification of immiscible polymer blends. The nanoparticles are able to change the interaction coefficient between two polymers and thus improve the compatibility between the polymer pairs.

Carbon nanotubes (CNT)

The discovery of carbon nanotubes (CNT) in 1991 opened up a new era in materials science. CNTs are long cylinders of covalently bonded carbon atoms which have extraordinary electronic and mechanical properties. The structure of CNT is similar to graphite, the sp2 hybridized CNT has each of its atoms bonded to three neighbouring atoms in a hexagonal array. CNT is at least 100 times stronger than steel, but only one-sixth as heavy, so nanotubes could strengthen almost any material. Nanotubes have thermal and electrical conductivity than copper. There are two types of CNTs, singlewalled (SWCNT) and multi-walled nanotubes (MWCNT) depending on the number of cylinders of graphene sheet as shown in Figure 5. In SWCNT, a single graphene layer rolled up into a cylinder. MWCNTs consist, two or more cylinders of graphene sheets. These cylindrical structures have few nanometre diameter, tens of microns long, with most end capped with half of a fullerene molecule. CNTs can be synthesised using three methods which include arc discharge, laser ablation and chemical vapor deposition (CVD). The mechanical electrical and thermal properties of SWCNTs and MWCNTs are given in the Table 1

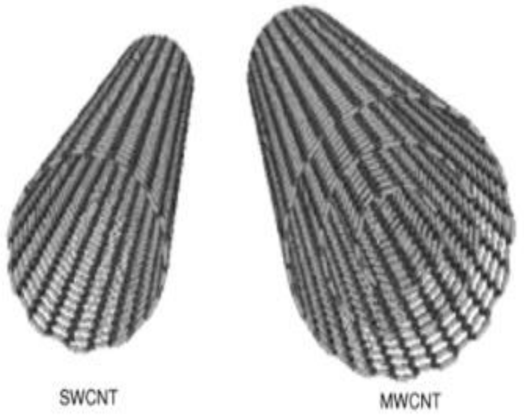

Figure 5 Type of CNTs: SWCNT and MWCNT

Table 1 Properties of SWCNTs and MWCNTs

Properties	Typical value
Specific gravity	1.8g/cm^3
Elastic modulus	0.3-1 TPa
Strength	10-60 GPa
Resistivity	5-50μΩcm
Thermal conductivity	300 Wm^{-1}K^{-1}
Thermal stability	>700 °C (in air); 2800 °C (in vacuum)
Specific surface area	200-400m^2/g

Carbon nanotube based polymer nanocomposites

Nowadays, carbon nanotubes (CNTs) have emerged as the most promising nanofiller for polymer nanocomposites. For the last two decades, a lot of research work has been done on CNTs as filler for polymer nanocomposites. Carbon nanotubes have been widely used due to their outstanding properties including good internal structure, high strength, stiffness and thermal and electrical conductivity. The incorporation of CNTs into a polymer matrix leads to excellent conductivity, good improvement in mechanical property and superior morphological stability. In 1991, CNT was first reported by Iijima. In 1994, Ajayan et al. reported that the first CNT based polymer nanocomposites. Earlier, carbon blacks, silicas, clays, and carbon nanofibers (CNF) have been extensively used as fillers to enhance the mechanical, electrical, and thermal properties of polymers. CNT has a unique combination of mechanical, electrical, and thermal properties which make them excellent candidates to substitute or complement the conventional Nano fillers in the fabrication of multifunctional polymer nanocomposites. The polymeric materials in general show advantages such as light weight, high strength, anti-rust, and ease of process ability. CNT based polymer nanocomposites exhibit good mechanical properties, morphology control and excellent conductivity characteristics. Polymer nanocomposites containing CNTs are promising materials for high-performance application such as sensors, aerospace parts, and electromagnetic shielding components. The reinforcing effect can be quantified through the percolation threshold. At the percolation threshold, the CNT-CNT network like structure is achieved. At this concentration of CNTs, the rheological properties of the nanocomposites change from viscous fluid to solid like behaviour. When the concentration of conductive fillers reaches percolation threshold, the conductivity of the nanocomposites tremendously increases due to the formation of the conductive percolating network. In all preparation methods CNT gives mixtures of the nanotube with different chiralities, diameters, and lengths along with the different amount of impurities and structural defects. It is very difficult to reproduce the experiment with these inconsistent nanofillers and virtually impossible to compare results between different researchers. Another great task in nanotube/polymer composites is the efficient dispersion of nanotube in the polymer matrix. There are several techniques to improve the dispersion of CNTs in polymer matrices, such as by optimum physical blending, in situ polymerisation and chemical functionalisation.

Processing of CNT based nanocomposites

The common methods of preparation of polymer nanocomposites are given below:

a) Melt blending
b) Solvent casting
c) In-situ polymerization

a) Melt blending

Melt blending is one of the most economical and environmentally friendly methods of preparation of nanocomposites and it’s a choice for most industries. In melting mixing method, the polymer and the nanoparticle mixture are heated to form a melt. The mixer imparts high shear forces which is helping to break apart the filler agglomerates and dispersing them uniformly in the polymer matrix. Figure 1.6 shows the Brabender internal mixer for melt blending of the polymer. The melting point of the polymer is one of the important parameters which aids in effective blending in this method without degrading the polymers. The melt mixing is successfully used for dispersion of CNTs in the various matrices, for example polystyrene, polypropylene and polyethylene. While, the meltmixing technique is simple but the issues of high shear force and higher temperature need to be properly addressed in order to avoid the weakening of nanocomposites. While high shear force facilitates CNT dispersion, it can also lead to the breakage of CNTs or even polymer chain scission. Therefore, the shear force needs to be optimized to achieve good dispersion without compromising the structural integrity of CNTs.

Figure 6 Brabender internal melt blending mixer

b) Solvent casting

The solution casting is the most common method to fabricate CNT-based polymer nanocomposites films. This method involves the, agitation (e.g. refluxing, mechanical/magnetic stirring, vigorous shaking, high shear homogenization, bath/probe sonication) of the nanoparticle in a polymer that is dissolved in a solvent before casting in a mould and evaporating the solvent. Figure 7 shows a schematic representation of solvent casting. It is important to note that this method is restricted to the polymers which are soluble in the solvent(s). The selection of solvent is largely governed by the solubility of the matrix polymer.

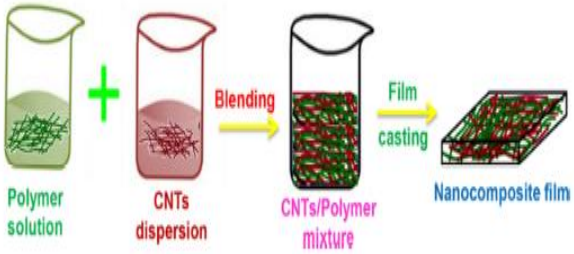

Figure 7 illustration of solution casting method

c) In-situ polymerization

In in-situ polymerization, nanotubes/nanoparticles are dispersed in the monomer which is then polymerized. Dispersants may be added to help in the de-agglomeration of the nanotubes/nanoparticles. In situ polymerization has the ability to allow the development of high CNTs-loading nanocomposites, facilitating good CNTs dispersion within the polymer matrix and ensuring excellent intimacy between CNTs and matrix polymers. The schematic representation of in-situ polymerisation is shown in Figure 8. This results in a stronger and more active interface between nanoparticles and polymer which is essential to the nanocomposite performance for structural, electronic, electromagnetic or electrochemical applications.

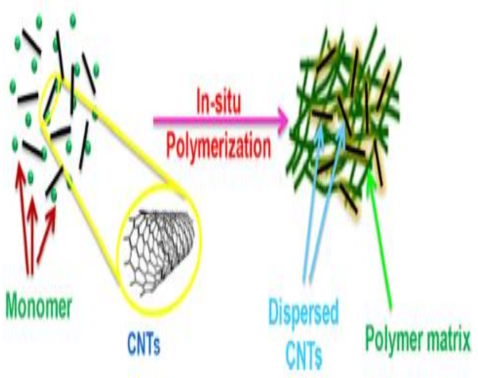

Figure 8 Illustration of in-situ polymerization process

ELECTROMAGNETIC INTERFERENCE SHIELDING

Basic theory of EMI shielding

Electromagnetic interference is disturbance to the normal and smooth working of the electrical circuit due to either electromagnetic induction or electromagnetic radiation emitted from an external source. Electromagnetic interference affect the smooth working of scientific devices, communication instruments, etc. EMI shielding is needed to protect the work space and environment from radiation coming from outside world. EMI shielding reduces the electromagnetic field in a space by blocking the field with barriers made of conductive or magnetic material. Due to the rapid increase in the number of power of sources and expanding the range of frequencies used, the task of screening these fields is becoming increasingly difficult. This is due to the fact that the miniaturized electronic circuits are necessary for the various complex systems. An increased miniaturization of electronic circuits reduces resistance to electromagnetic exposure. Shielding is one of the tools of electromagnetic compatibility, which should enable smooth collaboration of systems and electrical equipment and electronics with the electromagnetic environment. Therefore, selection of appropriate materials for the screens and their geometry has absolute significance. Conventional metal based EMI shields found certain drawbacks such as corrosion, heavy weight, poor processibility in corners and tip. In recent years, many efforts have been carried out by microwave engineers, scientist and technologist to develop EMI shielding material using conducting polymer composites as they are light weight, resistance to corrosion and have flexibility. Polymers and their composites, novel class of materials eliminate the disadvantages of conventional metal-based EMI shields. Due to their light weight, versatility, low cost, and processability, conductive polymer composites are attractive materials for EMI shields. The Electromagnetic interference shielding effectiveness of nanocomposite depend on mainly the conductivity and dielectric properties of the nanocomposites. This property can be achieved by incorporating the conducting nanofillers into the polymer matrix. The electromagnetic interference shielding effectiveness (SE) of a shielding material can be defined as the logarithmic ratio between the incident power (PI) and the transmitted power (PT) of an EM wave and is expressed in dB. It depends on the conductivity, dielectric properties, thickness of shielding material and applied frequency range of EM waves. The primary mechanism of shielding is reflection for which shield should possess sufficient electrical conductivity. A secondary mechanism of shielding is absorption which requires the presence of electric or magnetic dipoles.

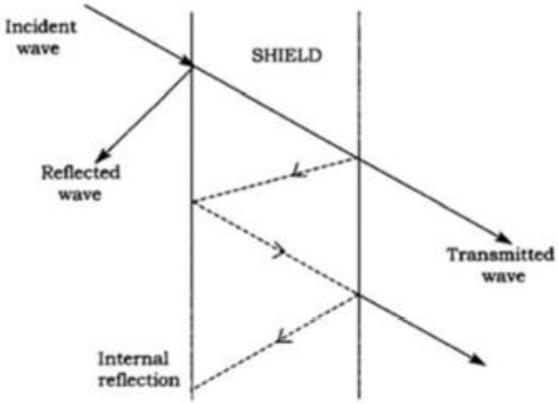

Figure 9 Mechanisms of EMI shielding [97]

The condition for efficient shield should possess either mobile charge carriers (electrons or holes) or electric and/or magnetic dipoles which interact with the electric (E) and magnetic (H) vectors of the incident EM radiation. For an incident electromagnetic wave that penetrates through a shield with a thickness t, reflection, the transmission and absorption of the wave can take place as shown in Figure 9.

The electromagnetic shielding effectiveness is the sum of shielding by reflection, absorption, and multiple reflections. The main mechanisms of EMI shielding are reflection and absorption of the electromagnetic radiation incident on the shielding materials. If the shield is electrically conducting, the incident EM wave interacts with the free electron on the surface and some EM waves reflected from the surface of the shield. If electric dipoles interact with the electromagnetic fields in the radiation, EM waves will be absorbed by the dipoles. When the shielding effectiveness is higher 10 dB, the shielding by multiple reflections can be neglected.

CONCLUSION

The effect of the addition of multiwalled carbon nanotube and PP-g-MA on the morphology, viscoelastic, thermal, dynamic mechanical, dielectric, electrical and EMI shielding properties of co-continuous polycarbonate/ polypropylene based blend nanocomposites has been carefully studied. Polypropylene is a semi-crystalline thermoplastic being used for a wide range of applications in packaging, automotive, containers etc. Polycarbonate is being used in various fields like electronics, medical, optical media etc. But low heat resistance and poor low temperature impact performance of PP, restrict its application to a limited range of service temperature. In order to overcome these drawbacks, blending of PP with thermoplastics having higher heat resistance and better impact is being practiced. Interestingly polycarbonate (PC) is an expensive engineering thermoplastic having high heat and impact resistance and so the blending of PP with PC can provide a new blend system which could be used in many applications in an economical way. In the last few decades, the addition of nano-fillers has gained a lot of interest in compatibilising immiscible polymer blends. Fillers such as CNT, nanosilica, nanoclay, graphene etc. are promising candidates for the modification of immiscible polymer blends. Carbon nanotubes have been widely used due to their outstanding properties including good internal structure, high strength, stiffness and thermal and electrical conductivity. The incorporation of CNTs into a polymer matrix leads to excellent conductivity, good improvement in mechanical property and superior morphological stability. In this work, multiwalled carbon nanotubes were introduced into co-continuous polycarbonate/polypropylene blends through melt compounding in an internal mixer. The morphologies of the neat blends, the blend nanocomposites and the dispersion states of the MWCNTs were carefully analysed. Both the neat blends and blend nanocomposites showed viscoelastic phase separation process where phase in phase morphologies could be observed due to viscosity disparity and Tg differences between the component polymers (PP and PC). Selective solvent extraction was used to analyse the co-continuous morphology with and without the addition of MWCNTs.

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