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Applications of the Polymer Matrix Nano Composite Material–A Review

Praveen Chamoli[1*] and A.V. Muley[2*]

[1]P. G student in MPAE Division, Division of MPA Engineering, Netaji Subhas Institute of Technology, Delhi University, New Delhi*
[2]Faculty, Division of MPA Engineering, Netaji Subhas Institute of Technology, Delhi University, New Delhi 110078*
E-mail: praveenchamoli67@gmail.com

Abstract–*The nanotechnology is a very popular area of research these days and many researches are going on in developing the suitable nanocomposites. In this paper we will discuss about the application of the polymer matrix composites (PMC) in different fields and also about its properties. The composites are those material which are made up by mixing two or more different materials having different properties. The Nano composites is made of polymer as a matrix and reinforced fibre like glass fibre and carbon fibre (of range below 100nm).This Nano polymer composites have very high potential and have wide range of application in many industries like in food packing industries, automobile, aerospace, electronic biomedical science etc. The PMC shows very promising mechanical and thermal properties.*

Keywords*: Nano particles, polymer matrix composites, applications, reinforced fibres.*

1. INTRODUCTION

In past few years there is strong focus on the fabrication, synthesis and development of the Nanocomposites. With advancement in the computer technology, it is very easy to predict and analyse the properties of Nano particles. This Nano composites are categorized on the basis of the type of matrix used such as metal matrix composites (MMC), ceramic matrix composites (CMC) and polymer matrix composites (PMC).The polymer matrix composites are widely used these days because when they are added with reinforced fibres (like carbon fibre, glass fibre, Al_2O_3 etc.) shows improved properties like light weight and also very good thermal, mechanical, chemical and electrical properties. The polymatrix composites can be further classified as thermoplastic, thermosetting and elastomer polymer composites. The properties exhibit by the Nano particles are more significant and improved as compare to the micro/macro level particles. In Nano scale the surface area to volume ratio is very high**[1]**due which these materials show different physical, mechanical, thermal and chemical properties from the materials of comparative large size.

The main aim of the paper is to show at what field the applications of polymatrix Nano composites are possible, these composite materials have very high potential to replace the conventional materials from the market because of its light weight and improved thermal and mechanical properties. The Japanese company Toyota was the first one which use the nanocomposites in automobile industries, they use the naylon-6[2] and founded that it exhibits improved mechanical and thermal properties[2,3]. In their work, they observe that by increasing the 4.2wt % clay, modulus get doubled and 50% more increment in the strength [3,4,5].

The one of most important feature of some polymer matrix composite is that they are environment friendly. This polymer matrix composites are biodegradable in nature. Because of this property it can be used as a packing rappers, cups, bottles etc. and help in reducing the large amount of plastic waste which is ungradable in nature. Some of the biodegradable polymer composites are polylactide (PLA), thermoplastic starch and cellulose etc.

History-The polymer composites are manufactured for many years for various application in aerospace automobile, construction etc. But due to the advancement in computer technology (like modelling and simulation of material is possible and also nano scale study can be done) the nano polymer composites are given special attention. This nano composite material must have atleast one dimension in the range of 10-100nm. The nano composite material shows very improved mechanical, thermal, chemical, and electrical properties as compare to the micro or macro level material, this is because of very small size of nanoparticles which leads to very high aspect ratio (surface area to volume ratio). The high aspect ratio is one of the reason due to which nano composite material shows very good and enhanced properties. The diameter of particles/ fibres and their surface area have inverse relationship with each other, if diameter decreases then surface area to volume ratio increases and vice-versa. The nano composites exists in nature for thousands of years, wood, shall and bones are the examples

of some of natural nano composite material which are made up of mixing two or more phases such as fibre and particles. Wood is composed of cellulose fibre and lignin matrix which make it a composite material. Lignin lies between the cellulose fibre and bind them together. Generally, particles are classified as particle layer and fibrous material. Carbon black, silica nano particles are categorized as nano particle layers and nano fibre, nano carbon tubes as fibrous material.

2. APPLICATIONS

As we have discussed, the polymer matrix composites have very high potential to be used in many applications because they are easy to produce, low cost, light weight and high mechanical, thermal and chemical properties. This polymer matrix Nano composite have many applications in different field like food packing, electronic and sensors, biomedical science, batteries and have many mechanical and thermal applications. We will discuss about each application in detail one by one with suitable industrial us.

2.1. Applications of Nano PMC on sensors

By using the carbon based nano-fillers as the reinforcement element in the polymer matrix can be used for the various applications. Some of the carbon based filler which are used in the polymer matrix are carbon black (CB), carbon nano tubes (CNT), graphene and carbon nano filler etc.**[6,7].**The CBN and graphene are most promising and effective nano filler carbon material because of its high aspect ratio which leads to the enhancement of polymer properties. The addition of nano carbon fillers opens the door for many applications in the field of electronic sensors, LED, solar cell and actuator. The sensing mechanism of carbon based nano PMC depends on the variation of external conditions such as mechanical deviations, gas absorption and temperature differences**[8]**. Due to the low cost, ease of preparation and easy availability and possibility of high potential to replace the conventional sensing material which are comparatively high in cost. This carbon polymer composite can be use as the mechanical sensor, gas sensor, humidity sensor and temperature sensor etc.[**9]**

2.1.1 Mechanical sensor

The carbonnanocomposite material is very promising for mechanical sensing application, they can use as strain sensor,**[10]**pressure sensor**[11]** and motion detection sensor[**12].** The strain sensitivity can be expressed as**[13]** Stain sensitivity (gauge factor) = $\frac{\Delta R}{R_o \varepsilon}$, where ΔR is the resistance variation due to applied mechanical strain.R_o is the initial resistance with no strain.ε is the applied mechanical strain. The carbon polymer composite exhibits high value of gauge factor as compare to the traditional sensors. Its value is usually about 2**[14]**. The pressure sensors are the kind of mechanical sensor which have very crucial application in microphone, tough screen, weigh balance etc. the pressure sensors based on functional graphene composite have very high variation to the pressure range from 100.84 KPas to .1729 KPas which make it suitable to use in detecting joint motion, breath and heart motion **[15]**.

2.1.2 Gas sensor

These sensors get to much attention not only because of its industrial application but also its vital role in preventing environment and human health**[16,17]**. It is very important to detect the harmful gases present in the environment so that it can be treated. The carbon Nano filler composite articles have very high potential to sense the different gases and different concentration of gases. They are very brilliant gas sensing element because of their high aspect ratio. More modification on sensing ability can be done by introducing the defects or by chemical doping**[18].** The gas sensors are of following type such as chemo resistance sensor, surface acoustic wave, quartz crystal base sensor etc. The mechanism of sensor is that when these are exposed to gas molecules it electrical conductivity changes, the oxidizing gas like O_2 and N_2 decreases the resistance of the sensors whereas reducing gas like ammonia (NH_3), ethanol (C_2H_5OH) increases the resistance of the sensor. Some of the polymers which are used in the sensing application are ethyl cellulose, polyvinylpyrrolidone (PVP) etc.**[19]** for sensing application at different temperature. Temperature and humidity also have impact on the performance of gas sensor.

2.1.3 Humidity sensor

The total monitoring over the humidity is very important with economic and environment point of view. The carbon based nano composites can also be used as the humidity sensor. In this composites the nano filler and the matrix both play very important role in determining the humidity level. The nano particles which used in humidity sensors are carbon black (CB) and polyvinylpyridine (PVP), because they are hydrophilic in nature which enable them to absorb some amount of water molecules**[20]**. These humidity sensors have the application in medical like in wound and skin pathology management and also in controlling microclimate humidity in clothing.

2.1.4 Chemical sensor

Some of the nano polymer matrix composite like**multi walled carbon nano tube (MWCNT) and polyaniline (PANI**)are the chemical sensors, these sensors can be used to determining the PH value between 1-13**[21]**. They heavy metal ions such as Cadmium ions, lead ions, mercury ions, Zinc ions, and Copper ions can easily be sensed by using these sensors.**[22]** They are also very suitable in determining the concentration of lead and cadmium race in water.

2.1.5 Bio Sensors

The carbon nano composites like graphene and CNT are very are very promising for bio-sensing point of view because of their compatibility with bio molecules. The graphene and CNT

shows very good sensitivity, stability and signal to noise ratio**[23]**. The nano composites have electrochemical properties which make them to be suitable for bio detection application such as detection of glucose, uric acid, protein maker, immonosensor etc. so by monitoring the concentration of above bio molecules and help in the diagnosis of many diseases. The carbon based nano composite improves the presently existing sensing technology and develop the future sensing application. More research and studies are still required in investigating the sensing mechanism of this composites. The low sensitivity and high selectivity towards the particular gas, irreversibility and contamination are the major issue that are needed to be overcome.

2.2 Applications in food packaging industries

Nano technology also plays a very crucial role in maintaining the quality, texture, taste and safety of the packed food products. The main aim of the packaging is to extend the viability of the product by preventing it from unwanted external factors such as microorganism, chemical contamination, oxygen, moisture and light. In recent time, the nano materials such as nanopolymers are replacing the conventional food packaging material (metal, glass and paper) because these nano composites are light in weight easily processible. There are around three thousand different type of natural and synthetic polymer and half of them have harmful impact on the human lives so we need to pay deep attention while choosing the polymer in food industries. The most frequent used polymers in food packaging industry are polyethylene (PE) and various types of polyethylene such as low density polyethylene (LDPE), high density polyethylene (HDPE), polyvinyl chloride (PVC), polyethylene terephthalate (PET) and polypropylene (PP)**[24]**.

High density polyethylene is used for packing milk bags and bottles, low density polyethylene is used to make plastic bags and containers. Polypropylene (PP) have high melting point and excellent chemical resistance which making it to suitable to filling with hot liquid. Polyehylene terephthalate (PET) have very good resistance property against the moisture and gases, so they are used in making various plastic container or bottles for carbonated drinks. The main focus is on to develop the polymer composite which are highly impermeable to the atmospheric gases like O_2, CO_2 and water vapour. Presently no composite material is perfectly permeable to atmosphere but in some case high barrier to diffusion of gases are undesirable such as in packaging of fruits and vegetables because they need continues supply of oxygen.

2.2.1 Applications of bio polymer in food packaging industry

Bio polymer are these polymers which are degradable in nature, it attracts to much attain towards food packaging or sustainable development. These bio polymers have carbon content which is derived from fossil resources. Under the action of humidity, temperature and exposer to oxygen these polymers decompose into the nature in the form of nontoxic and environment friendly material but the main issue with the bio polymer is that they have lower mechanical, thermal and humidity resistance/barrier properties, which does not suit it much for industrial use. In order to overcome these problems, the polymer at filled with nano particles. The properties of nano polymer composite depends on the size of nano particles, concentration of nano particles and type of poly matrix. Due to high surface area to volume ratio of nano particles improves the properties of the polymer composites. Some of bio nano filler are cellulose, chitosan and collagen they have excellent mechanical properties, high surface area to volume ratio and light weight.

2.3 Application in photovoltaic devices

Due to the growing demand of energy all over the globe, the renewable and sustainable source of energy get into the attention. As these source of energy are environment friendly and renewable as well as which reduce our huge dependency over the natural source of energy like petroleum, wood and coal. The photovoltaic energy source like organic solar cell (OSC) and light emitting diode (LED) is one of the example of clean energy source, they have power conversion efficiency up to 25%**[25]**. Only drawback is that they have high manufacturing coast and set up coat as compare to other energy source**[26]**. The carbon based nano filler in polymer matrix plays very crucial role in improving the efficiency and effectiveness of the photovoltaic devices. Polyphenylenevinylene (PPV) and polythiophenes are two major polymers which are used in the photovoltaic devices2**[27]**. The nanofiller carbon based material such as carbon nano tube (CNT), graphene and fullerene are used as the nano particles in the polymer matrix. These material have very high potential in the field of photovoltaic devices because of their properties like high electric constant, high charge mobilityand thermal stability**[28,29,30]**. The replacement of indium tin oxide (ITO) electrodes in photovoltaic devices (PV) with nanocomposites (MWCNT) and polyphenylenevinylene (PPV) polymer improves the performance of PV devices**[31].** The Indium Tin Oxide (ITO) are very popular transparent electrode but they are suffering from high cost, mechanical instability and lack of flexibility. The carbon based polymer have very high potential in replace these material from market. Theses carbon nano composite have many application in

2.3.1 Electrode

Carbon Nano Tubes (CNT) are very favourable electrode in electronic industry and can be used in solar cell. The CNT have the properties like high electric conductivity, excellent mechanical properties and good transparency in the thin film due to which this CNT have the potential to replace the conventional material in PV devices**[32,33,34]**. CNT can be used in the form of MWCNT, SWCNT, and FWCNT and have the properties like high optical transmittance which make

it appropriate for use as transparent conducting electrode (TCEs) in PV devices and display application. Similarly, graphene shows the properties like excellent mechanical and electrical properties and good thermal and chemical stability which makes the graphene very suitable in photovoltaic application as they can be use as electrode**[35,36]**.

2.3.2 Active layer

The light emitting diode (LED) and organic solar cell (OSC) revolutionized the lighting industry because of their high efficiency but the LED and OSC are needed to be encapsulated by the layer to improve the life span of OSC. Because LED and OSC shoe high tendency towards the moisture and oxygen which lead to the damage and short life duration of these devices so high level of encapsulation is very much required to overcome he humidity and gas permeability by this layer. So all attention goes toward the nano composites polymer material in which material like phosphor and zeolites is used as the nano filler material. The phosphor particles show he emission property in the visible domain upto a UV excitation so these phosphor polymer composite can be used as lightning device such as LED and can be used as a multifunctional coating for organic solar cell (OSC). Similarly, zeolite has very good water/moisture barrier property so it can be used as the encapsulated material. Zeolite is also known as alumina-silicate, it has very good water sorption property due to its porous structure**[37]**.

2.4 Applications in Lithium Battery

In present scenario so much advancement is going on in electronic industry which demand the storage device with high current densities, long life and cheaper. All the natural renewable energy resource like wind energy, ocean energy, wave energy and solar energy requires reliable storage system so that this energy can be used during demand. The lithium-ion- battery are the commonly used storage system which operating voltage of 4V, capacity ranging from 700-2400 mAh and specific energy 100and 150 Wh/kg**[38]**. But they have limited storage capacity short life and safety also it suffers specific challenges like availability of lithium metals, low stability of on anode material and flammability of electrolyte material. The carbon based organic polymer can overcome all the limitation of LIB, these carbon polymer batteries have the potential to sufficiently power the 140W desktop and PC for data backup system**[39]**. The doping/mixing of nano particles in the polymers can improve the properties magnificently. The properties of anode and cathode in LIB totally depends on the morphology, size of nano particles and electron conductivity of nano particles. The nano material such as carbon nano tubes (CNT), graphene, fullerene, silicon based material, electric conducting polymer nano composites have been used as an anode material. The deposition of this carbon nano particles into the polymer provides the effective path for transportation of electron and Li ion diffusion. The presence of nano particles leads to the high storage capacity, stability and long life cycle. Polymer is the host for making the electrode in lithium ion battery (LIB), which play equally important role in the performance and storage carrying capacity of the battery. The most common polymer used in the LIB are polyacrylonitrile (PAN), polymetyl methacrylate (PMMA), polyvinyl chloride (PVC) etc. these polymers exhibits very good mechanical strength, heat resistance, good flame retardant property and chemical stability. These polymers are used in form of gel or blend.

2.5 Applications as a flame retardant material

The presence of polymer in our daily life ease everything in our life, this polymer are light in weight, low cost and have many applications in day to day life. But these hydrocarbons based polymer like polyvinylchloride (PVC), polystyrene and polymethylmetacrylate (PMMA)**[40**] are flammable in nature, they catch fire very easily and produce excessive heat smoke and noxious gases which are very harmful to environment and human health can also lead to human death. The nanomaterials have very high potential in the application of flame retardant, these nanoparticles help in reducing the propagation rate of flame and hence slow down the rate of burning. The silicon based compounds like silica, silicones, organosilanes, silicates and silsequioxanes are very much suitable to be used as flame retardant material in the polymers**[41]**. The silicon particles have non porous and smooth surface area**[42]** and also have high surface area to volume ratio which ensures the good interaction between polymer and nano fillers even at relative low loading which enables the better interaction between the polymer and the fillers. The filler produces the char structure through a catalytic process and aid in flame retardant. The nanoparticles show the improved flame retardant property through enhanced char formation which leads to the increase in ignition time, reduce the combustion rate and reduce release no heat and smoke during firing. The flame retardant mechanism of the nano filler particles in the polymer composite based on physical barrier effect. The char structure formed by the nano filler material during the burning is thermally stable and at as a barrier to heat transfer between the material and flame. So this does not allow the further propagation of fire and act as a shield during burning.

3. DISCUSSION

The various applications of the nano polymer matrix composites (NPMC) have been discuss above. They have very good future scope and can be used in various another application. The table below gives some information about the application of NPMC in different field.

Table 1: Shows various applications of nano polymer matrix composites with their respective polymers and nano fillers.

S. No.	APPLICATIONS	POLYMERS	NANO FILLERS
1	Sensors	Ethylcellulose, polyvinylprrolidone (PVP), polyaniline.	Carbon nanotubes (CNT), carbon black (CB) graphene and nano fillers.
2	Food packing	Polyethylene (PE), poly vinyl chloride (PVC)and polypropylene (PP)	CNT, graphene, CB, cellulose, chitosan and collagen
3	Photovoltaic (PV) devices	Polyphenylenevinylen (PPV) and polythioplene	Zeolite, phosphor, CNT, graphene and fullerene.
4	Flame retardant	PVC, polymetylmetacrylate (PMMA)	silicon based compound like silica, silicones, organosilanes silicate and silsequioxanes
5	Lithium battery	PVC, polyacrylonitrile (PAN), polymetylmetacrylate (PMMA)	Silicon based nano filler, CNT, graphene and fullerene
6	Biopolymer composites	Polyvinyl chloride (PVC), Polyethylene (PE) and polypropylene (PP)	cellulose, chitosan and collagen

Above we have also discussed that some of nano materials are biodegradable in nature and are environment friendly. But most of the nano polymer composite material are bad for human health. The nano material like graphite can cause skin disease and respiratory problems. This nano materials have medical application in which they are introduce into the human body for disease detection, for imagining and for treatments but most of time they leave harmful impact into human body. The size of nano material is comparable to human cells due to which human immune system fails against them. This nano materials can penetrate deep into human lung tissue and can damage them. So we need to introduce new carbon nano material which should be less toxic and can be used safely in industry without any major harmful impact on human health. So we need to study and research on the new form of nano materials.

4. CONCLUSION

The review on the various application on the nano polymer matrix composite material have been discuss above. The purpose of the paper is to mention potential applications of nano polymer matrix composite material in different field. Most of the properties of the nano polymer matrix composite are based on the morphology, size of nano fillers and interface between polymer matrix and nano filler material. The interfacial layer between polymer and nano filler need more investigation and research, the information obtained can be used in future technology.

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