

# Polymer-Based Magnetic Nanocomposites: Synthesis, Properties and Applications

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## ABSTRACT

The developing field of nanotechnology is quite exciting. Nanotechnology can be defined as any technology that operates at the nanoscale and has a wide range of applications. A lot of research has been done on nanomaterials. One area of this research is nanocomposites. They need the mixing of two distinct materials, each with unique features, and at least one of the resulting materials must be nanoscale in size. Polymers The new family of sophisticated materials known as polymer-carbon nanotube nanocomposites has several uses in both industry and medicine. Because adding nanometric inorganic chemicals to polymers can improve their properties, there are several uses for doing so. These objects have very high mechanical, electromechanical, and thermoelectric qualities. This study discusses Magnetic Polymer Nanocomposites and Their Uses.

**KEYWORDS:** Polymeric Matrix, Magnetic Approach, nanocomposites, polymer nanocomposites, applications.

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## 1. INTRODUCTION

Nanotechnology was believed to be too costly for practical application just a few years ago. Nanoparticles (NPs) can now be synthesized for a variety of biotechnological and medicinal uses. Because of their remarkable versatility, NPs have had a substantial impact on a wide range of sectors and scientific fields. NPs have at least one dimension that is between 1 and 100 nanometers. A lot of interest in this type of nanoparticles has been generated by biomedical applications for MNPs, including biosensors, drug delivery, theragnostic, imaging, and bioremediation. MNPs are an intriguing new class of nanomaterials that can be manipulated by subjecting them to a magnetic field. Scientists and materials scientists have been fascinated by nanomagnets, but biologists are also interested in these materials' special qualities [2]. These qualities can be further improved by working in concert with another biomolecule, like a polymer.

Depending on their structure and the polymerization process that produced them, macromolecules known as polymers can have a variety of distinctive

characteristics. These macromolecules serve as a substrate for the nanoscale deposition of other materials. By mixing MNPs with a polymeric matrix (PM) (PNCs), polymer nanocomposites can be produced. PNCs work in concert to modify microscopic dynamic processes, producing unusual macroscopic characteristics. Advanced materials with qualities that can be adjusted at the nanoscale have been made possible via nanotechnology. Because they combine the benefits of polymers with the special qualities of nanoscale fillers, polymer-based nanocomposites have garnered significant scientific and technological attention among these materials. The materials that come from the incorporation of magnetic nanoparticles into polymer matrices show both magnetic responsiveness and polymeric processability.

High surface area, magnetic responsiveness, and tunable magnetic behavior are characteristics of magnetic nanoparticles, especially iron oxide nanoparticles like magnetite (Fe<sub>3</sub>O<sub>4</sub>) and maghemite (γ-Fe<sub>3</sub>O<sub>4</sub>). By incorporating them into polymers,

composites that react to external magnetic fields can be created while maintaining the polymeric materials' flexibility, low density, resistance to corrosion, and ease of processing.

### 1.1. Nanomaterials

One billionth of a nanometer is equivalent to every 10<sup>-9</sup> meters, or nm. Nanomaterials are therefore defined as materials with a single unit diameter ranging from 1 to 1000 nanometers. A subfield of nanotechnology that employs a materials science methodology is called nanomaterials research. A material's size, form, and chemical composition frequently dictate its special qualities.

### 1.2. Carbon nanotube

They were only recently identified as a novel kind of material, and its electrical, thermal, and structural characteristics are remarkable. They have an electrical conductivity similar to that of copper, making them as conductive as the metal in terms of heat and electricity. In the future, computers, circuits, and nanoelectronic devices will be able to perform incredible things with them. Additionally, carbon

nanotubes have exceptional mechanical qualities: they weigh only one-sixth of steel while being 100 times stronger. Scientists are still researching carbon nanotubes for microprocessors and other electrical transistors.

### 1.3. Nanocomposite

It is a solid multiphase material having one, two, or three dimensions less than 100 nanometers (nm), or structures with repetitive distances between the phases that comprise the material at the nanoscale. a nanocomposite. Although porous media, colloids, gels, and copolymers can all be included in this term in its broadest sense, it is most widely known to refer to the solid combination of a bulk matrix and one or more nano-dimensional phases having distinct properties due to structural and chemical variations. Examples of each of the three main types of nano composites are displayed in Table 1. Ceramic-based nanocomposites

1. nanocomposites with a metal matrix
2. nanocomposites with a polymer matrix

### Different types of Nanocomposites

| Types   | Examples                                                                                                                                                        |
|---------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Ceramic | Al <sub>2</sub> O <sub>3</sub> /SiO <sub>2</sub> , SiO <sub>2</sub> /Ni, Al <sub>2</sub> O <sub>3</sub> /TiO <sub>2</sub> , Al <sub>2</sub> O <sub>3</sub> /SiC |
| Metal   | Fe-Cr/Al <sub>2</sub> O <sub>3</sub> , Co/Cr, Fe/MgO, Mg/CNT                                                                                                    |
| Polymer | Thermoplastic/thermoset polymer/layered silicates, polyester/TiO <sub>2</sub> , polymer/CNT, polymer/layered double hydroxides.                                 |

**Table 1: Polymer Nanocomposites and their Applications in Electronics Industry**

The mechanical, electrical, thermal, optical, electrochemical, and catalytic properties of a nanocomposite will differ from those of its constituent materials. A catalytic activity of less than 5 nanometers, less than 20 nanometers for softening hard magnetic materials, less than 50 nanometers for refractive index alterations, and more than 100 nanometers for achieving super paramagnetism or limiting matrix dislocation movement are suggested size limitations for these characteristics.

### Characterization of Nanocomposites

The prepared samples will be characterized using the following techniques:

- **X-Ray Diffraction (XRD):** To determine crystalline structure and phases.
- **FTIR:** To identify functional groups and polymer–nanoparticle interactions.
- **SEM:** To study surface morphology and nanoparticle distribution.
- **TEM:** To determine nanoparticle size, shape, and dispersion.

- **VSM:** To evaluate magnetic properties such as saturation magnetization, coercivity, and remanence.
- **TGA:** To determine thermal stability and degradation behaviour.
- **DSC:** To study thermal transitions of the polymer nanocomposites.
- **Mechanical testing:** To determine tensile strength, elongation, hardness, and related properties where applicable.

### 1.4. Polymer Nanocomposites:

Polymers can only be utilized as structural materials when reinforced because they lack mechanical qualities. Low tensile and impact strengths are characteristics of polymer materials. Polymer nanocomposites provide an alternative to traditionally filled polymers. Polymer nanocomposites, such as polyacetylene, polythiophene, and polypyrrole, contain nanoscopic inorganic particles that are usually 10–100 Å in at least one dimension. Because of their nanometer-sized inorganic filler, inorganic filler

nanocomposites offer substantially better characteristics than pure polymers or conventional composites. The mechanical, thermal, electrical, and magnetic properties of polymeric nanocomposites are significantly influenced by the interactions between the PM and nanofillers. When the filler is distributed throughout the polymer matrix, its surface area creates a "interaction zone" that alters the behavior, morphology, space charge distribution, and bond dispersal of the polymer.

### 1.5. Magnetic Nanocomposites

The size and shape of the NPs utilized as reinforcing fillers must be carefully regulated to guaranty that MNPs are dispersed uniformly throughout the PM. Data analysis is greatly facilitated by magnetic nanocomposites with equally sized particles. Using nanoparticles of ferromagnetic and ferromagnetic materials implanted in extended matrix materials, integrated functional systems with extra magnetic properties have been made possible.

An external magnetic field can be used to treat complex disorders using nanocomposites with superparamagnetic characteristics, which are highly suggested for biomedicine. Magnetic nanocomposites (MNCs) can be utilized to target and regulate drug delivery using an external magnetic field, thereby treating challenging conditions like Parkinson's disease. Bioremediation is the process of removing heavy metal ions from water using magnetic nanoparticles.

#### Objectives

1. To synthesize polymer-based magnetic nanocomposites
2. To characterize the synthesized nanocomposites
3. To investigate the effect of magnetic nanoparticle concentration
4. To study the interaction and dispersion of magnetic
5. To evaluate the potential applications

#### Research Methodology:

The study will adopt an experimental research design to synthesize polymer-based magnetic nanocomposites and investigate their structural, morphological, magnetic, thermal, and mechanical properties.

#### Materials:

Polymer matrix: PVA, PMMA, PVDF, epoxy, polyaniline, or another suitable polymer.

Magnetic nanoparticles:  $\text{Fe}_3\text{O}_4$  (magnetite),  $\gamma\text{-Fe}_2\text{O}_3$  (maghemite),  $\text{CoFe}_2\text{O}_4$ , or  $\text{NiFe}_2\text{O}_4$ .

The required quantity of magnetic nanoparticles will be added to the selected polymer matrix. Different nanoparticle concentrations may be prepared to study their effect on composite properties.

## 2. Synthesis of Polymer-Based Magnetic Nanocomposites

Particle distribution, interfacial bonding, shape, and the performance of the finished material are all significantly impacted by the synthesis process.

### 2.1. Solution Blending

In solution blending, magnetic nanoparticles are added after the polymer has been dissolved or dispersed in a suitable solvent. After using sonication, stirring, or other dispersion methods, the mixture is dried.

#### General procedure:

1. Dissolution of polymer.
2. Preparation of magnetic nanoparticle dispersion.
3. Combination of polymer and nanoparticle phases.
4. Mechanical stirring or ultrasonication.
5. Removal of solvent.
6. Drying and formation of the nanocomposite.

Although the process is rather straightforward, there may be issues with residual solvent and solvent recovery.

### 2.2. Melt Blending

Melt blending involves mixing magnetic nanoparticles with a molten thermoplastic polymer using equipment such as an internal mixer or twin-screw extruder.

The principal advantages are:

- Solvent-free processing
- Industrial scalability
- Compatibility with conventional polymer processing

However, homogenous dispersion may be difficult due to high viscosity and nanoparticle aggregation.

### 2.3. In Situ Polymerization

Magnetic nanoparticles are dispersed among monomers and then polymerized during in situ polymerization.

Strong interactions between the polymer phase and magnetic nanoparticles can be produced with this technique, which may also improve control over the distribution of nanoparticles.

### 2.4. In Situ Formation of Magnetic Nanoparticles

Chemical precipitation or similar reactions can also directly produce magnetic nanoparticles within a polymer matrix.

For instance, iron oxide nanoparticles can be created in a polymeric environment by the controlled precipitation of iron salts.

This method can increase distribution and lessen the agglomeration of nanoparticles.

## 2.5. Sol–Gel Method

Hybrid polymer–inorganic systems can be created using the sol–gel method. An inorganic phase is produced inside or surrounding the polymeric structure by regulated hydrolysis and condensation processes.

The technique works well for creating materials with regulated shape and chemistry.

## 2.6. Surface Functionalization

One key tactic for enhancing compatibility with polymer matrices is surface modification of magnetic nanoparticles.

To enhance the surface of the nanoparticle, functional groups can be added.

- Dispersion
- Polymer–particle interaction
- Chemical stability
- Biocompatibility
- Resistance to aggregation

Common surface-modification strategies involve polymers, surfactants, silane-based compounds, or other functional coatings.

## 3. Properties:

### 3.1. Magnetic Properties

The way magnetic polymer nanocomposites react to an external magnetic field is their most crucial feature.

Vibrating sample magnetometry (VSM) and superconducting quantum interference device magnetometry are frequently used to study magnetic characteristics. Important parameters include:

- Saturation magnetization
- Remanent magnetization
- Coercivity
- Magnetic susceptibility

These factors are significantly influenced by the size and concentration of nanoparticles.

### 3.2. Mechanical Properties

The mechanical performance of polymer matrices can be altered by adding magnetic nanoparticles.

Improvements could take place in the following areas, depending on the concentration and dispersion of nanoparticles:

- Tensile strength
- Young's modulus

- Hardness
- Wear resistance

## 3.3. Thermal Properties

Through interfacial effects and physical interactions, magnetic nanoparticles can affect the thermal stability of polymers.

Polymer-chain mobility may be limited and resistance to thermal degradation may be enhanced by an evenly distributed inorganic phase. But the real impact is contingent upon:

- Polymer chemistry
- Nanoparticle surface chemistry
- Loading percentage
- Dispersion quality
- Processing conditions

Thermal analysis is therefore essential when designing magnetic nanocomposites for high-temperature applications.

## 3.4. Electrical and Electromagnetic Properties

The incorporation of magnetic nanoparticles can significantly modify dielectric and electromagnetic characteristics.

When magnetic and electrically conducting components are appropriately combined, polymer nanocomposites can exhibit enhanced electromagnetic absorption and shielding.

Potential applications include:

- Electronic equipment protection
- Communication systems
- Microwave devices
- Radar-related technologies
- Electromagnetic interference shielding

Conducting polymer/magnetic nanoparticle systems are especially interesting because they can provide simultaneous electrical and magnetic loss mechanisms.

## 4. Applications

The design of advanced electronic and optoelectronic devices is heavily influenced by nanotechnology. Electronic devices are now on the nanometer scale in terms of size. Polymer-based nanocomposites have a wide range of potential applications in these fields, and their use has been proposed in a variety of contexts.

- Electroluminescent and electrocatalytic devices, batteries, smart windows and memory devices all make use of chemical sensors.
- Photovoltaic (PV) cells and photodiodes, supercapacitors, printable conductors, light emitting diodes (LEDs), and field effect transistors are other potential applications.

- Carbon nanotubes in insulating polymers have been studied for their electrical conductivity. EMC shielding, transparent conductive coatings, electrostatic dissipation of electrostatic charge and a variety of electrode applications are all possible uses.
- In addition to gas sensors, biosensors, and chemical sensors, conjugated polymers with various nanoscale filler inclusions have been studied. Metal oxide nanowires, carbon nanotubes, gold, silver, nickel, copper, platinum, and palladium nanoparticles are some of the nanofillers used.
- There has been an increase in the use of graphene in electronics, similar to that of carbon nanotubes. Sheets of graphene may be able to replace silicon as Moore's law reaches its limit.
- Large flexible solar panels can be made at a low cost using polymer-based solar cells. Its only drawback is that it is significantly less efficient than commercial solar cells[15]. Solar cells have been constructed with cadmium chalcogenides, such as CdS nanoparticles embedded in polymers.
- Nanocomposites of polymers and semiconductors promise a new generation of hybrid materials with numerous applications, such as optical displays, catalysis, photovoltaics and gas sensors.

## 5. Conclusion:

This article provides a succinct overview of polymer nanocomposites and their application in the electronics sector. Although there are still problems with carbon nanotube dispersion and alignment when creating polymer nanocomposites, data currently available indicates that their electrical and thermal conductivity values make them excellent choices for usage as TIMs and in applications requiring electrically conducting pads. Researchers are searching for more effective techniques to transfer the high thermal and electrical conductivity of carbon nanotubes to the polymer matrix in the nanocomposites. However, polymer/carbon nanotube nanocomposites could be evolved into an amazing nanomaterial that helps reduce the size of electrical devices.

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