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Magnetic Polymer Nanocomposites: A magical material for crosswind

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Abstract:
Polymers have had an enormous impact on science and technology, and their interest relating to the development of new macromolecular materials has exponentially increased. Polymer nanocomposites, materials based on a polymeric matrix covalently coupled to reinforcement, display properties of both components. In the aerospace industry, polymer nanocomposites are attractive due to their promising characteristics, among which lightness, mechanical and thermal resistance, radiation and corrosion resistance, and conductive and magnetic properties stand out. The use of them, instead of metal-based materials, has allowed the optimization of design processes and applications in order to provide safer, faster, and eventually cheaper transportation in the future. This comparative review collects the most relevant and prominent advances in the development of polymer nanocomposites with aerospace applications starting from basic aspects such as the definition of polymer nanocomposite to more specialized details such as synthesis, characterization, and applications, in addition to proposing new research branches related to this topic.

1. Introduction:

Components used in the aircraft sector must be built of materials that can withstand extreme temperatures, be lightweight, have a high level of durability, and be able to withstand electromagnetic interference (EMI) [1]. Polymers are among the most often utilized materials for this purpose. The inexpensive cost, diverse synthesis, and broad range of qualities this material may offer—including light weight, electrical conduction, strong heat resistance, wear, and corrosion—give it some advantages over other materials [2]. Magnetic polymeric nanocomposite is the term used to describe composites consisting of a polymeric matrix and a reinforcing material that has magnetic properties. The reinforcing material can take the form of nanometric-sized fibers, particles, or flakes [3]. Materials science and engineering are involved in nanotechnology, which is revolutionizing a wide range of industries, including waste management, crossswind , energy, information technology, electronics, textiles, and medical and transportation. Development of novel materials with improved chemical, physical, and thermal properties in comparison to existing materials will be made possible by this field [4,5]. These materials will also be stronger, lighter, and more durable.

The nanocomposite is often reinforced with metallic nanoparticles (MNPs). A submicron particle with a diameter of less than 100 nm is known as a nanoparticle (NP) and is researched in the subject of nanotechnology [15]. The efficiency of EMI resistance is intimately linked to the electrical conductivity of these MNPs, which make them an exciting class of metal oxides that can be magnetized by an external field [7]. For crossswind applications, this is why employing polymeric nanocomposites reinforced with MNPs is quite advantageous. A nanocomposite can also be created by functionalizing or encasing MNPs in organic or inorganic substances [5,8].

Nanocomposite materials can be synthesized in a variety of ways. The variables that affect them include the utilization site, the dimensions and form of the composite material, the kind of reinforcing material, and the accessibility of resources like in situ precipitation, grafting, blending, chemical vapor deposition (CVD), and molding [9]. The enhanced qualities of the new material also require a thorough investigation, using characterization methods like Transmission Electronics Microscopy (TEM) and Atomic Force Microscopy (AFM) that aid in estimating the size of the reinforcing nanomaterial [10-13].

Composite materials improve the aircraft system by lowering the weight of the aircraft, which lowers the

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cost of fuel per passenger. Reminding people that glass fiber, carbon fiber, and aramid fiber are the three most popular reinforcements for composite materials is crucial. Presently, MNPs are often investigated as a component of a composite for aircraft applications [4].

The volume of the composite material can have 20–80% reinforcement, but often less than 50% [14]. In its most basic form, a functional material can be created by appropriately adding reinforcement to a polymeric matrix. By utilizing the filler's nanoscale nature and capabilities, this reinforcement can typically significantly increase the material's performance [16–17].

The term "magneto-polymeric materials" [19], also referred to as ferrogels [20], refers to a new class of multifunctional materials called MPNs that combine the characteristics of conventional polymers and magnetic materials (ferrimagnetic and/or ferromagnetic particles mixed or embedded in a matrix) [21].

A non-magnetic (polymer) matrix, such as a polymer matrix, solvent, or curable hydrogel, can be chosen based on the method utilized to create the printed magnetic parts in order to create MPNs [28]. In order to produce extremely proficient attractive materials, attractive MNPs were "doped" into polymer materials [29]. These attractive MNPs were made of an inorganic problem (usually superparamagnetic press oxide Fe_3O_4 or γ-Fe_2O_3), or "delicate" metallic iron, but also "hard" attractive materials, such as Ni, Co, FeN, FePd, FePt, etc. These material classes are of great interest because of their prospective applications in bioremediation [32], drug delivery [23], sensing, enzyme immobilization, DNA extraction, and catalysis [30, 31].

Polymers' enormous progress has fueled its use in a variety of industries, including structural, automotive, marine, crossswind , and military applications. Performance and the potential degree of deterioration are the most important considerations when employing any composite material. These elements will mostly rely on how long you stay in and how you interact with your surroundings. Because of the various processes that can take place, such as the breaking of significant bonds within the macromolecule, the deterioration of polymeric materials will involve changes in their physical and chemical composition. The materials that result from these modifications typically have inferior properties than the original material. The degraded materials will eventually lose their useful life and will not contribute to the mechanical qualities. This is why certain polymers, or their compounds, when employed outside, need to adapt well to the environment [33].

One of the most crucial requirements for any polymer or composite used in crossswind applications is its ability to withstand heat and flames. According to research in this area, flame properties of epoxy nanocomposites that have been specially modified outperform those of traditional composite materials [34].

Composite material thermal degradation is contingent upon the clay's charge, content, and type of surrounding gas. The impact factors and thermal stability of several matrices modified by montmorillonite clay were examined in a review of the literature by Leszczynska et al. [35].

2. Materials and method

2.1 Manufacturing of Nanocomposites using Magnetic Polymer

MNP creation using MNPs is the most effective method for creating internal order in polymer matrices. Various procedures, including molding, co-precipitation, in situ precipitation, blending, and grafting, have been developed to create MNCs. Injection is a simple method for transferring patterns via soft lithography, combining magnetic fillers with polymeric precursors and hardening them in molds to generate precise shapes or structures. Molding allows for more material to pass through cavities more quickly [37].

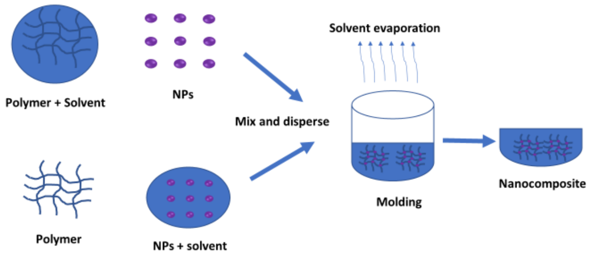

Figure 3.1. Diagram illustrating the molding process

2.2 The Co-Precipitation

Coprecipitation is an easy and convenient method of synthesizing iron oxide nanoparticles from aqueous salt solutions. It involves synthesizing salt species like Fe^{2+} and Fe^{3+} in an alkali

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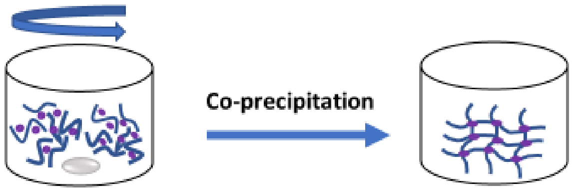

Figure 3.2. Diagram illustrating the co-precipitation technique.

solution without oxidizing conditions. Supersaturation of the metallic oxide in the solution takes place for the reactant to reach NPs of a particular size [37].

2.3 In-Situ Fall Formation

In situ precipitation method is a popular technique for synthesizing MNPs in solvent-free or solvent-based systems. It involves inserting nanoparticles into a polymer matrix in the presence of precipitation media, resulting in MNCs. The accessible pore volume is decreased when inorganic nanoparticles selectively precipitate within the porous matrix.

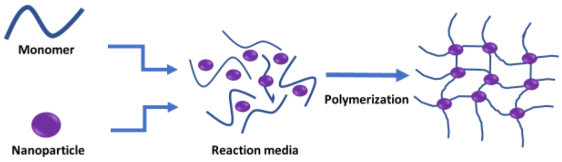

Figure 3.3. Diagram illustrating the process of in situ polymerization.

Magnetic composites can be created by embedding magnetic particles in a non-magnetic matrix using in situ polymerization. Chitosan hydrogel and MNPs were used to create MCs and solar steam was generated using nano Fe_3O_4 on MoS_2 nanosheets functionalized with polydopamine for efficient separation and recyclability.

2.4 Mixing

To produce hybrid magnetic loaded hydrogel networks, MNPs are physically encased in a polymeric matrix. This method keeps NPs from clumping together. Melt mixing is a more flexible method that fixes MNPs in the polymer matrix. Early findings on the manufacture of magnetic nanocomposites involved blending NiNRs into the ABS matrix and letting the solvent evaporate.

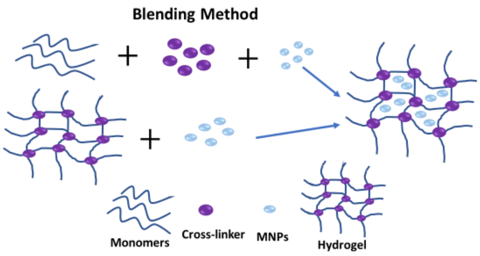

Figure 3.4. Diagrammatic illustration of the blending process.

2.5 Methods of Grafting

The "grafting-onto" method involves altering polymer chains and surfaces of MNPs to create magnetic polymeric matrixes. A new technique for attaching carbon nanotubes to carbon fiber via ester linkage allowed for the formation of a hierarchical CNT-CF reinforcing structure. The main variables in the production of nanocomposites vary between synthetic approaches.

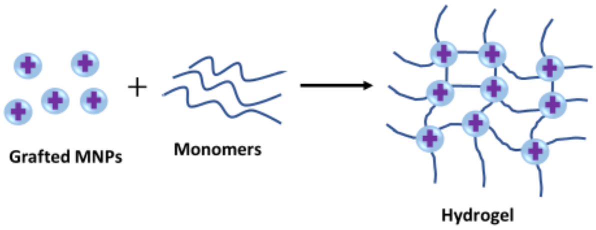

Figure 3.5. Diagrammatic illustration of the grafting process.

3. Result and discussion

3.1 Characterization of Polymer Nanocomposites

Characterization of polymer nanocomposites involves determining characteristics and analyzing structural and morphological aspects. Due to the small size of nanostructures, it is challenging to apply and manipulate well-established approaches. Combining various analytical methods is necessary to make results more understandable.

3.1.1 UV- Vis spectra analysis

ZnO particles were characterization by UV-Visible Spectrophotometer 1900i Shimadzu. Before putting the sample in the UV-Vis Spectrophotometer, ZnO sample diluted with water and ethanol because ZnO nanoparticles is soluble in water and ethanol, the sample solution was directly placed in spectrophotometer due to which the absorption of ZnO nanoparticles was recorded in the transmittance mode in the region of 200-800nm by using UV-Vis light and the spectrum of the sample is visible on the screen which is displayed 334 nm.

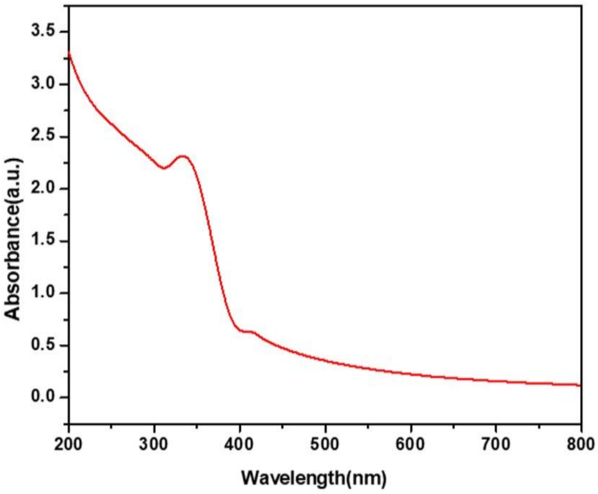

Fig: 4.1 UV-Vis spectrum of synthesized ZnO nanoparticles

3.1.2 Optical bandgap analysis

A UV-Vis spectrum of synthesized nanoparticles is determined by the UV-Vis spectrophotometer. We got the absorbance of the synthesis ZnO NPs at 340 nm and the band gap is found as 3.7 eV. Band gap of ZnO NPs were calculated from UV-Vis spectra.

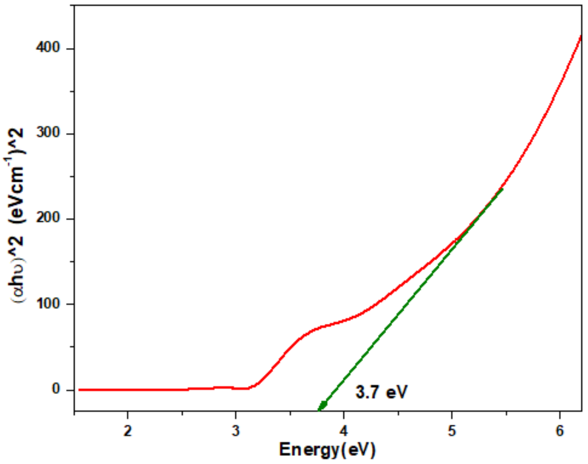

Fig:4.2 Band gap of synthesized ZnO nanoparticles

The optical absorption measurement near the fundamental absorption edge is a standard method for estimation of the band gap energy. The dependence of optical absorption coefficient with the photon energy helps to study the band structure and the type of transition of electrons. Using the absorption data, the optical absorption coefficient (α) can be deduced by applying the Beer-Lambert's law:

$$\alpha = 2.303 * A/e$$

where A is the maximum absorbance, and e is the sample thickness (e = 0.003cm).

The inter-band absorption theory shows that, the absorption coefficient near the threshold versus incident energy, is given by the following Pankove's relation:

$$\alpha h\nu = B\,(h\nu - Eg)^n$$

Where B is the probability parameter for the transition and Eg the optical gap energy. For allowed direct transitions, the coefficient n is equal to 1/2 and for indirect allowed transitions n=2. Owing to the direct band gap, the crystal under study has an absorption coefficient (α) obeying the following relation for high photon energies ($h\nu$):

$$\alpha h\nu = B(h\nu - Eg)^{1/2}$$

The Eg value corresponding to direct band gap transitions can be calculated via the $(\alpha h\nu)^2$ versus $h\nu$, using the formula:

$$(\alpha h\nu)^2 = B(h\nu - Eg)$$

The values of Eg were estimated from the intersection of the extrapolated linear part of the $(\alpha h\nu)^2$ curves with energy axis. Figure 10 shows the variation of $(\alpha h\nu)^2$ versus $h\nu$ before and after irradiation with laser beams for ZnO NPs.

4. Future Prospects Crossswind Applications

Polymer nanocomposites are being used in crossswind and military industries to prevent structural damage caused by EMF interference, ice, and corrosion. They can be used for EMI shielding, coatings & paints, and SHM.

EMI Shielding

Polymeric matrix composites coated with metallic magnetic nanoparticles are being used as EMI shielding materials in the aerospace sector. By combining the dielectric and magnetic properties of metals with carbon material, the polymer matrix creates an EMI shield that is lightweight and resistant to corrosion. An electromagnetic interference (EMI) shielding material made of a composite film of carbon, Fe_3O_4, and poly (vinylidene fluoride) (PVDF) was created. A polypyrrole/$Ba0.6Sr0.4Fe_{12}O_{19}$ composite was used to obtain 89% microwave absorption and an SSE value of 37.49 dB.

Coatings and Paints

Corrosion protection is crucial in the crossswind sector due to its impact on aircraft availability, safety, and structural integrity. Active protective coatings are an essential component of this strategy, but it can be challenging to predict when corrosion would start and how much structural damage could occur. Paints and coatings based on polymer matrix nanocomposites supplemented with an inorganic phase are being developed for this purpose. $CoFe_2O_4$/PANI magnetic

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additions are being synthesized as a possible corrosion preventive agent, and electrochemical impedance spectroscopy shows encouraging results after 100 days of immersion in saline or acidic conditions. Polyurethane and hydroxyapatite nanoparticles have anticorrosive capabilities, and a PVDF-HFP/SiO_2/CNTs coating with anti-icing and superhydrophobic qualities was created by Hou et al. After soaking in salt water for 192 hours, the epoxy coating with a weight percentage of 12 weight percent PANI-GON exhibits the maximum corrosion resistance of 2.70 106 Ω cm2. Nanocomposite coatings made of graphene oxide nanosheets (GONs) and epoxy-based polyaniline (PANI) were produced using in situ polymerization. These coatings have antifrosting and antifouling capabilities and can delay the production of frost for up to 2700 seconds at -18 °C.

Table 4.5. Synopsis of polymer nanocomposites' applications in aerospace

Application of Nanocomposite	Polymer Matrix	Reinforcement	Properties	Ref
EMI shielding	PVDF	Fe_3O_4/carbon	Lightweight	[61]
	PLA	Ag	Multiple scattering	[60]
	Epoxy resin	Iron, cobalt, nickel, and iron oxide	High strength and non-heavy	[58]
	PPy	$Ba0.6Sr0.4Fe_{12}O_{19}$	Low-cost and resistant	[62]
	PAN and PU	Ni-Co	Intrinsic conductivity and magnetism	[59]
	PLAUs	Fe3O4	Shape recovery in a magnetic field	[63]
	Epoxy resin	CNTs	High resistance	[64]
	Epoxy resin	$EDFe_3O_4$ CNTs/rGF	High EMISE value	[65]
Coatings and paints	PANI	$CoFe_2O_4$	Anticorrosive properties	[66]
	PU	MHAPs	Anticorrosive properties	[67]
	Epoxy-PANI	GONs	Anticorrosion and antifouling properties	[68]
	P(poly(ethylene glycol) methyl ether methacrylate-co-glycidyl methacrylate)	Fe_3O_4	Antifrosting property	[69]
	PVDF-HFP	SiO_2/CNTs	Anti-icing and superhydrophobic properties	[70]
SHM	PMDS	PZT	Superior piezoelectric behavior	[71]

5. Conclusion

Polymer nanocomposites are becoming increasingly important in various sectors, especially in the crossswind industry where metal-based components are still widely used. They offer lighter and more durable components that are resistant to fatigue, corrosion, and radiation. Synthetic and manufacturing processes have been applied to generate nanocomposition parts, but it is important to ensure that reinforcement is distributed uniformly throughout the polymeric matrix. Characterization techniques such as, UV- Vis spectrophotometer and Band gap. They have a bright future in crossswind due to their durable qualities that make them easier to select than traditional metals or their alloys, and synthetic techniques need to be developed at both laboratory and industrial sizes to fully utilize their potential. Eco-environmental characteristics should be developed based on these procedures to lessen environmental harm to lessen the impact of these materials.

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