Nanocomposites: Preparation, Properties, and Applications

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Abstract: Defined as a multiphase solid material with one, two, or three dimensions of less than 100 nanometers (nm), or structures with nano-scale repetitive intervals between the distinct phases that comprise the material, nanocomposites have over the years become one of the most popular areas of interest for current research and development in nearly all technical disciplines. This article provided a detailed definition of nanocomposites, before delving into in-situ polymerization, solvent-assisted solution blending, and molten or melt homogenization techniques which are the three types of nanocomposites' preparation. After discussing the mechanical, electrical, flame retardancy, thermal, barrier, and rheological properties of nanocomposites, the study also discussed in detail the numerous applications of nanocomposites which include but not limited to the following: energy storage, civil structures, defence and aerospace, environment remediation, electronics, agriculture and food, automobiles and textiles, as well as biomedical medicine and drugs. The research later concluded by observing that the worldwide production of nanocomposites is estimated to exceed 600,000 tonnes, and is set to cover so many important areas within the next few years.

Keywords: Nanocomposites, nano-technology, nano-fillers, nano-particles, synthesis, in situ polymerization, melt homogenization, solution blending

I. Introduction

Over the years, nanotechnology which deals with particles on the nanometer scale that are at least one dimension, has gained a lot of prominence among students and researchers on material science. Defined as comparatively new materials that are made from a variety of polymers and nano-size fillers that are organic and inorganic, nanocomposites are innovative materials in their purest characteristics with dispersed nanofillers in a matrix, and also having incomparable fundamental properties. Nanocomposites can also be defined as materials whose polymer matrix is integrated with fillers known as nano-particulates which range from 10 to 100 nm at the dispersed phase. Consisting of an organic polymer matrix implanted with particles that are inorganic, all nanocomposites have a minimum of one of their dimensions in nano range.

Rajani, Chauhan, and Dave (2021), explained that a nanocomposite is an innovative material that has dispersed nanofillers in a matrix, whose structure is a matrix filler combination, where the filler-like particles, fibers, or fragments are surrounded and bound together as discrete unit by matrix. They pointed out that the term nanocomposites have numerous materials right from three-dimensional metal matrix composites, to two-dimensional lamellar composites and nanowires of single-dimensional to zero-dimensional core-shells which represent many variations of mixed layered materials.

Nanocomposites which consist of the combination of more than one phase with diverse structures, with at least one of the phases at between 10 to 100 nanometres, have attracted enormous interest to scientists due to their desired mechanical and physical properties including fast bio-degradability, enhanced strength, smoothness, flammability, reduced absorption of gas, as well as resistance to corrosion, heat, and wear. They are very good reinforcement materials because of their exceptionally high aspect ratio or high surface area to volume ratio which makes them to be different from the regular composite materials.

According to Okpala (2014), nanocomposites are materials with a nanoscale structure that improve the macroscopic properties of products, and their importance cannot be over-emphasized, unlike conventional materials like metal used in oil and gas pipelines which have high corrosive nature, nanocomposites are corrosion resistant. The structure of nanocomposites according to Kumari, Rao, and Akhila (2019), is a combination of matrix and filler, where the "fillers like particles, fibers or fragments surrounds and binds together as discrete units in the matrix."

The increase in thermal stability, gas barrier resistance, and improvement of mechanical properties are some of the advantages of nanocomposites over pure polymers, this is because the introduction of nanofillers like layered silicates that have elevated aspect ratio greatly transform the polymer's macroscopic properties. Although the synthesis of nanotechnology for the production of new composites has gained wide acceptability over the years, it is quite pertinent for researchers to develop highly improved bio-degradable and sustainable reinforced composites.

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II. Preparations of Nanocomposites

Nanoparticles which are acquired from natural resources require some treatments as the physical mixture of layered silicate and polymer cannot easily give rise to nanocomposites, as a result of separation into discrete phases. This is because the weak physical interphase between inorganic and organic constituents results in reduced thermal and mechanic properties. However, nanocomposites display distinctive properties when compared to conventional composites, as the unique interactions between the composites that are layered silicate and the polymer gives rise to the two phases (organic and inorganic) to be dispersed at the nanometer level.

For the preparation of nanocomposites with suitable properties, it is pertinent that the nanoparticles will be dispersed homogeneously. Thomas et al. (2014), observed that it is quite intricate to prepare nanocomposite because it is possible for phases to experience segregation during processing, as the rigid polymer which has elevated strength and modulus, as well as increased melting temperature, cannot be dissolved in organic solvents, as it is thermodynamically unfavorable to combine it with the flexible polymer.

However, according to Okpala (2013), the preparation of nanocomposites – a process also referred to as exfoliation can be achieved through the dispersion of nanomer nanoclay into a host polymer, generally at less than 5wt% levels. He explained that exfoliation can be "facilitated by surface compatibilization chemistry, which expands the nanoclay platelets to the point where individual platelets can be separated from another by mechanical shear or heat of polymerization. "The preparation of nanocomposites can be achieved in three different ways: in-situ polymerization, solvent-assisted solution blending, and molten or melt homogenization techniques.

In-Situ Polymerization Technique

The in-situ polymerization technique of nanocomposites' preparation involves the insertion of a monomer or polymer precursor inside layers of clay before layered silicate platelets are expanded into the matrix, through a process known as polymerization, thereby leading to the production of properly exfoliated nanocomposites that has wide range of applications. According to Amin (2013), to achieve in-situ polymerization, nanofillers are swollen inside the liquid monomer solution which leads to the formation of polymer around and inside the intercalated layers. He observed that polymerization can be started either by the initiator, through the incorporation of a curing agent, or temperature increment, if it is adequately reactive.

For the generation of polymer nanocomposites through in-situ polymerization technique, the layered silicate as depicted in figure 1, is first of all swollen in monomer before the commencement of the monomer polymerization. The process of polymerization commences with the application of radiation, heat, initiator diffusion, or through a selected catalyst. The produced structure is therefore substantially intercalated or exfoliated because monomer is available both inside and outside of the filler interlayers.

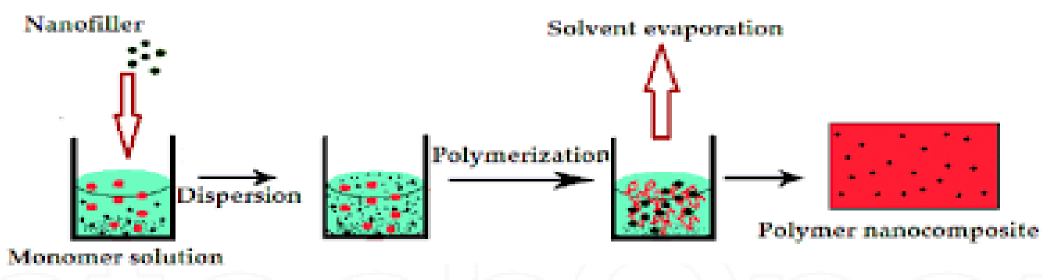

Figure 1: In-situ polymerization

Zapata et al. (2008), observed that in-situ polymerization of nanocomposites entails both the "monomer and the catalyst between the clay layers, and polymerization takes place in the gap, so as polymerization progresses the d-spacing between the clay's layers increases gradually and the dispersion state of the clays changes from intercalated (the ordered of layered silicate gallery is retained) to exfoliated (delamination with destruction of the clay sheet order)." The advantages of the polymerization technique according to them include: only one step synthesis of the metallocene polymer nanocomposites, enhanced compatibility of the clay and the polymer matrix, as well as improved dispersity of clay.

Although that in-situ polymerization technique enhances proper dispersal of nanoparticles inside the polymer matrix, it is generally employed in polymers that cannot be prepared by solution methods because of the highly toxic nature of the applied solvents, as well as in polymers that are too expensive to prepare. Also, due to less difficult thermodynamic requirements when compared to other techniques of nanocomposites' preparation, in-situ polymerization has been adjudged the best synthesis technique for clay or polyolefin nanocomposites. This is because the tethering effect enables nanoclays that have a chemically active surface to combine with the polymer chain during the polymerization process.

Solvent Assisted or Solution Blending Technique

The solvent-assisted or solution-blending technique of nanocomposite preparation involves a solvent system with soluble polymer and swellable nanofiller layers. Generally applied with less toxic solvents like alcohol, chloroform, water, as well as acetone, this is the easiest technique of nanocomposite preparation, as based on the excellent interaction between the polymer and solvent, diverse quantities of nanoparticles can be easily dispersed.

According to Amin (2013), when the nanofiller solutions and polymer are mixed together after the nanofiller is swollen in a solvent, the solvent inside the interlayer of the nanofiller is displaced by the polymer chains intercalate. While observing that the disadvantage of the solution blending technique is the use of very expensive organic solvents that are environmentally unfriendly, he pointed out that nanocomposites are achieved when the intercalated structure remains upon the removal of the solvent.

As depicted in figure 2, the processes involved in solution blending technique of nanocomposites preparation include swelling, intercalation, as well as evaporation.

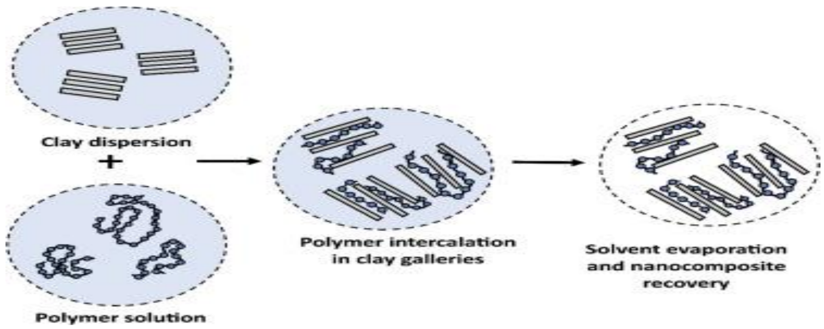

Figure 2: Solution blending technique

Molten or Melt Intercalation Technique

Molten or melt intercalation technique of nanocomposite preparation has improved substitution for solution mixing, and is regarded as environmentally friendly as no solvent is required. Although it requires proper supervision of the dispersion of nanoparticles as a result of their faster agglomeration when compared to other synthesis techniques, the dispersion process includes the following: early wetting of the agglomerates by the polymer, weakening of the agglomerates through polymer chains infiltration, agglomerates dispersion through erosion and rupturing, as well as nanotubes distribution into the matrix.

Oliveira and Machado (2013), while explaining that melt intercalation technique is based on trial-and-error experiments to examine diverse process states in order to optimize dispersion, noted that based on the degree of layers separation, either exfoliated or intercalated nanocomposites can be achieved based on the compatibility that exists between polymer and layers surface.

As depicted in figure 3, the process involves blending and annealing.

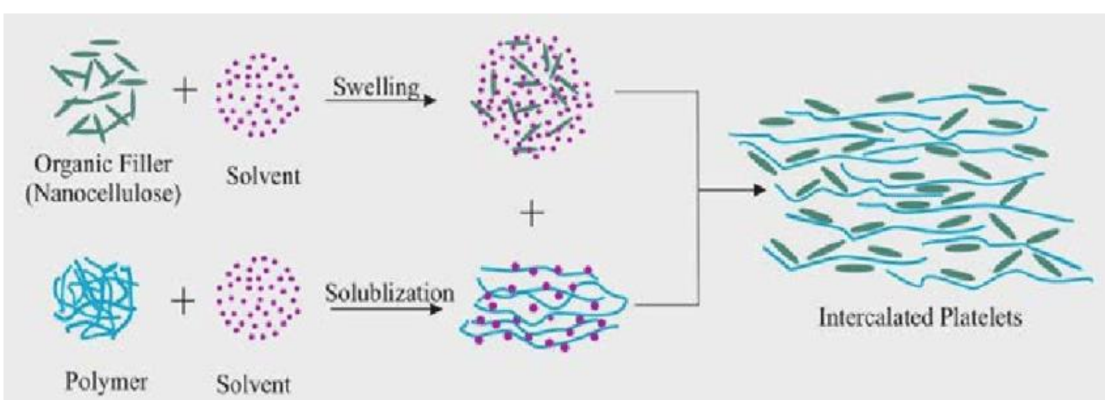

Figure 3: Melt intercalation technique

According to Fawaz and Mittal (2015), the melt intercalation technique is a distinctive method of synthesizing thermoplastic nanocomposites that entails the following, annealing of polymer matrix at elevated temperature, filler addition, as well as achieving uniform distribution through kneading of composites. However, they pointed out that although the increased temperature applied in the process can adversely affect the filler surface, that the approach is quite economical as it is compatible with industrial processes like extrusion and injection moulding.

III. Properties of Nanocomposites

Liny and Patil (2021), observed that morphology and interfacial features of the materials decide the properties of temperature, magnetic properties, charge capacity which nanocomposites possess. They explained that they also "possess superior mechanical properties like high dielectric constants which are flexible, easy to process, and powerful." Since nanocomposites are clay, carbon, or polymer, or a mixture of those materials with nanoparticle building blocks, they still maintain the discrete features of the fillers and matrix which distinguishes them from alloys, this is because their ultimate properties are dependent on the following: filler geometry in the matrix, filler composition and arrangement, and the interphase bonding of the matrix and filler.

According to Carmago, Satyanarayana, and Wypych (2009), nanocomposites present remarkable resilience, as they can withstand bending to large angles and re-straightening without impairment, this is because they don't undergo plastic deformation like metals, as well as carbon fibers' brittle fracture. As they have a tremendous elevated surface to volume ratio which intensely alter their properties when contrasted with their bulk sized counterparts, nanocomposites exhibit high optical transparency, improved flexibility, mechanical strength, thermal stability, flame retardancy, electrical conductivity, modulus and dimensional stability, enhanced tensile strength and barrier properties, as well as decreased permeability of water, gas, and hydrocarbon. This is because the properties of nanocomposites like electrical conductivity, magnetic properties, as well as temperature are determined by the material's interfacial characteristics and morphology.

With visible disparity in their mechanical, electrical, barrier, and thermal properties which is dependent on the polymer and clay combination, the characteristics of the polymer and nanofiller, as well as the configuration of the produced material, the critical changes in nanocomposites are triggered by size confinement, quantum mechanisms, and predominance of interfacial phenomena and not by the magnitude in size reduction order. Din et al. (2019), observed that nanocomposites provide diverse opportunities that create global interest in them, as they exhibit distinct properties with enhanced performance, thereby attaining the developing demands of scientific and technological advances.

In addition to having a high surface-to-volume ratio for loading biomolecules like enzymes, the nanocomposites also have high mechanical strength, high electrical conductivity, redox reactivity, and catalytic activity. When compared to their base polymer and customary filler counterparts, nanocomposites also have the following characteristics:

a. Improved mechanical properties (e.g. strength, modulus, and dimensional stability);
b. Reduced permeability to gases, water, and hydrocarbons;
c. Improved thermal stability and Heat Distortion Temperature (HDT);
d. Reduced thermal expansion coefficient;
e. Enhanced flame retardancy;
f. Reduced smoke emissions;
g. Improved chemical resistance;
h. Better surface appearance;
i. Higher electrical conductivity; and
j. Improved optical clarity.

Mechanical Properties

Tensile strength, modulus, dimensional stability, and elongation are some of the mechanical properties of nanocomposites, which are influenced by the surface morphology and the type of material employed in production. The enhancement of its mechanical properties can be ascribed to the similarity that exists between the nanofiller and polymer, alongside the nano fillers' increased rigidity and high aspect ratio.

The first revealed illustration of thermo-mechanically reinforced polymer nanocomposites according to Usuki (1993), was that of nylon-6 layered silicate hybrids produced by Toyota Central Research, which showed concurrent enhancements in flexural strength and heat distortion temperature while not adversely affecting the impact properties. While explaining that nanocomposites have improved mechanical properties like strength, modulus, dimensional stability, toughness, and electrical or thermal conductivity, decreased gas etc., Liny and Patil (2021), noted that they possess "superior mechanical properties like high dielectric constants which are flexible, easy to process, and powerful." They pointed out that the enhanced mechanical properties of nanocomposites such as stability have led to a rise in heat deflection temperature, as polymer-clay nanocomposites have a remarkable decrease in solvent update and liquid and gas permeability.

Although the addition of nanoparticles to polymer matrix leads to improvement in mechanical properties as it improves scratch resistance and hardness, the micro hardness, tensile and flexural strengths are enhanced with the addition of Cloisite 30 B nanoclay in E-glass fibers and epoxy. According to Thomas et al. (2014), it has been observed that tensile strength and break elongation were improved in nanocomposites depending on compatibilization and filler loading, as exfoliated polymersilicate systems have been realized to portray enhanced mechanical properties when compared to the conventionally filled systems.

The improvement of mechanical properties of nanocomposites can be achieved by reinforcement through the addition of nano-fillers, as the improvement level is dependent on the nature of both the filler and matrix, the level of interaction between the filler and matrix, the method of fabrication, as well as the size of the fillers.

Electrical Properties

The alignment of conducive nano-fillers in a structure, aspect ratio, and dispersion are some of the factors that electrical properties of nanocomposites is dependent on, as polymr nanocomposites display conductive properties for electrical applications. According to Muller et al. (2017), the electrical conductivity of Carbon Nano-Tubes (CNT) in insulating polymers has also been a crucial topic, as areas of applications include transparent conductive coatings, electro-mechanical actuators, super capacitors, and several other applications of electrodes. They noted that Nano composite based polymer with various nanoscale filler inclusions has been studied for sensor applications like gas sensors, biosensors and chemical sensors, and that the nanofillers employed include "metal oxide nanowires, carbon nanotubes, nanoscale gold, silver, nickel, copper, platinum and palladium particles."

Nanocomposites with carbon nano-tubes have decreased driving voltages and increased energy densities which are enhanced electrical properties. However, the production of low weight materials that are employed in electrostatic discharge and coating of electrical conductors are some of the major interest of polymer nanocomposites, because of the outstanding difference between the dielectric and electrical properties of numerous nano-particles.Conductive nanocomposites exhibit properties of conductivity for applications in electrical and electronics materials which include: electrostatic dissipation, super capacitors, electromagnetic interference shielding, diverse electrode applications, printable circuit wiring, transparent conductive coatings, as well as electromechanical actuators, and electrostatic painting.

Flame Retardancy

Phosphorus-based materials and some metal hydroxides like magnesium hydroxide and alumina usually weaken the mechanical properties of nanocomposites while enhancing flammability resistance. According to Kumar and Krishnamoorti (2010),polymer nanocomposites based on nanoplatelets and nanotubes (and nanorods) have been suggested to provide a paradigm for enhanced flame resistance due to the reduced gas transport, radical scavenging activity of the high surface area nanoparticles, increased melt viscosity, and stable char formation, and therefore leads to the prevention of continuous surface regeneration of fuel for the combustion process. They explained that "critical to the stable char formation is the presence of a percolated filler network structure to provide a mechanical framework of high-temperature stable nanoparticles."

Jiang et.al (2015), successfully created a novel nanocomposite using an Intumescent Flame Retardant (IFR), which was originally produced as the flame-retardant intermediate, and montmorillonite that had been modified by Cetyl Trimethyl Ammonium Bromide (CTAB) and collagen. XRD and FT-IR were used to describe the material's structure and characteristics. By using three different tests—the vertical burning test, the limiting oxygen index (LOI) test, and the cone calorimeter test—the flame retardant was added to leather, and its effects on the flame-retardant characteristics of the leather were examined. The results showed that the novel nanocomposite has good flame-retardant properties and can enhance the fire retardancy of leather effectively.

Thermal Properties:

The thermal properties of nanocomposites can be analyzed by Differential Scanning Calorimetry(DSC). From the weight loss on heating the nanocomposites, the thermal stability can be calculated. The heat resistance of nanocomposite on external loading can be measured from the Heat Deflection Temperature (HDT). The dependence of HDT on clay content has been investigated by several researchers. The nanocomposite with good thermal conductivity have multiple applications, such as printed circuit boards, thermal interface materials, heat sinks, connectors and high-performance thermal management systems. The excellent thermal properties of nano composites has been verified via various studies.

Kherroub etal (2015), carried out a synthesis of poly (furfuryl alcohol)/montmorillonite nanocomposites by direct in-situ polymerization. The aim of their study was to produce poly (furfuryl alcohol) nanocomposites using 12-montmorillonite, an organically modified clay from Algeria. Infrared spectroscopy (IR) was used to confirm the production of poly (furfuryl alcohol), and X-ray Diffraction (XRD), Transmission Electron Microscopy (TEM), and Thermogravimetric Analysis (TGA) were used to characterize the generated nanocomposites. The nanocomposites showed higher thermal stability compared to pure polymer, and the mechanical properties presented interesting and promising results.

Barrier Properties:

Nanocomposites have very good barrier property against gases because of their high aspect ratio, and by the creation of a tortuous path that retards the progress of the gas molecules through the matrix resin. Inside the nanocomposite structure, the presence of the filler introduces a tortuous path for diffusing penetrants. The permeability is reduced because of the longer diffusive path that the penetrants must travel in the presence of filler. The polyimide nanocomposite containing a small fraction of layered silicate exhibit barrier property against small gases such as oxygen, carbon dioxide, helium, nitrogen and ethyl acetate vapors.

Saritha et al. (2012), modelled the gas barrier properties of nanocomposites using the composite theories of permeation and the tortousity factors were predicted. The analysis and calculation of breakthrough times showed the effectiveness to be utilized as potential gas and as Volatile Organic Compounds (VOC) barrier materials.The barrier properties of nano composites can be improved by increasing sonication time. The nanocomposites' much increased qualities are related to their high dispersions, which drastically improves corrosion factors and barrier properties (Jiang et al., 2016).

Rheological Properties:

The flow behavior of Polycaprolactone (PCL)/nylon 6 nanocomposite was significantly different from the corresponding neat matrices. The viscoelastic properties of nanocomposites are important in relation to composite processing and composite dynamics and microstructure analysis. Krishnamoorti and Giannelis (1997), were the first to describe the rheological properties of in situ polymerized nanocomposites with end-tethered polymer chains.

In another study by Mantia and Dintcheva(2006), the findings indicate that nanocomposites have rheological properties under normal processing circumstances that are comparable to those of the virgin polymer, allowing for their usage in processing procedures involving both shear and elongational flows. The rheological properties of hybrid nanocomposites increases linearly with the percentage of the charge used. The rheological behavior of hybrid nanocomposite polymers depends on fiber content, fiber length, fiber orientation, fiber-to-matrix bonding, fiber configuration and filler. In summary, nanocomposites exhibit other multifunctional properties such as high surface-to-volume ratio for loading of biomolecules such as enzymes, high electrical conductivity, redox reactivity, and catalytic activity.

IV. Applications of Nanocomposites

The applications of nanocomposites are overwhelming and encompass the engineering sector, healthcare, environmental protection, etc. The practical applications of nanocomposites ranges from drug delivery, bio sensing, tissue engineering, bones regeneration, enhancement of mechanical properties, gas sensor applications, cellular imaging, thin film capacitors for computer chips, solid polymer electrolytes for batteries, automotive engine parts and fuel tanks, impellers and blades, Oxygen and gas barriers, food packaging, etc.

As a matrix to which nanoparticles have been added to improve a particular property of the material, the favourable properties of nanocomposites have caused researchers and manufacturing companies to apply them in diverse areas. Nanocomposites allow design and characteristic choices that are impossible with conventional composites. Based on their light weight and multi-functionality, they cater for the needs without compromising aesthetics and comfort of textiles. In smart textiles, nanocomposites are applied in sensors, actuators, mediators, biosensors, thermoregulation, energy storing, and harvesting elements, among others.

Due to their improved mechanical, electrical, and thermal properties, polymer nanocomposites and the materials used in their production are commercially available and applied in a variety of industries, including the automotive, military, food, electronics, and leisure (Bogue, 2011).

As depicted in figure 4, the various fields of nanocomposites' application can be grouped into the following broad areas:

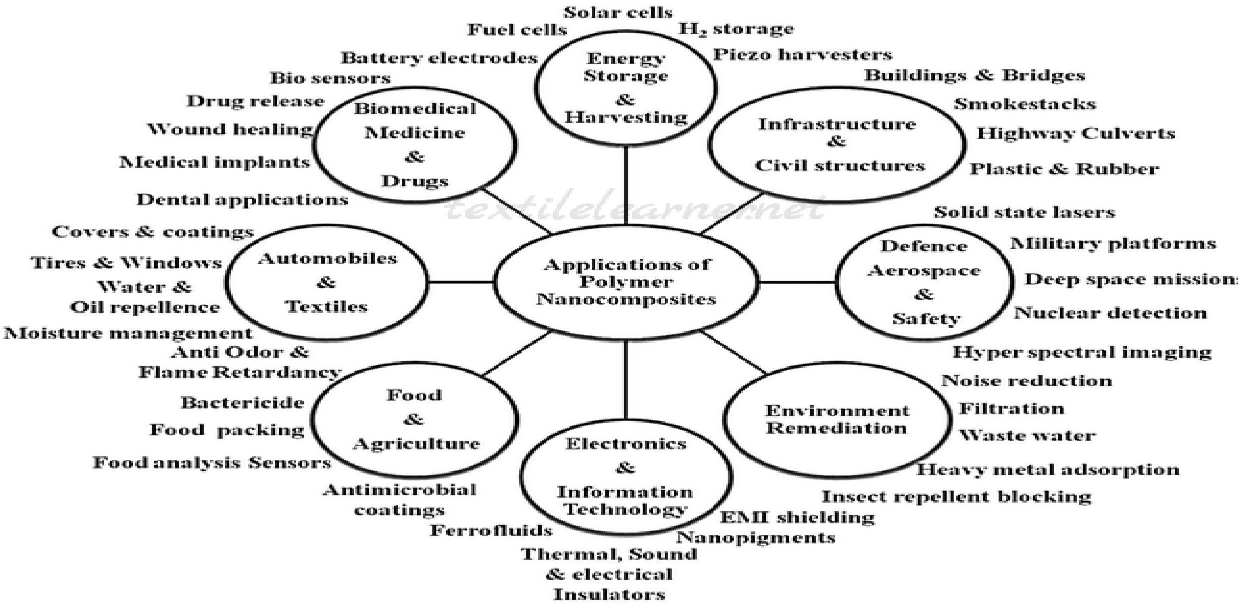

Figure 4: Various applications of polymer nanocomposites.

Source: Kiron (2021)

Bio-Medical Engineering Applications

Nananocomposites have been utilized in the biomedical applications like wound healing, bone tissue engineering, antimicrobial agents, drug delivery systems and biosensors. Scientists have already made some breakthroughs in the treatment of spinal cord damage by promoting cell development. Other areas of applications in bio-medical engineering include: magnetic nanoparticles and nano components that are sensitive to enzymes that target brain tumors; intelligent nanoparticle samples for intracellular drug administration and gene expression imaging; quantitative points for detecting and quantifying human brain cancer, etc. According to Balaji et al. (2017), different types of nanocomposites are utilized in biomedical applications like tissue engineering, drug delivery, and cellular therapies. They noted that a "range of natural and synthetic

polymers are used to design polymeric nanocomposites for biomedical applications including starch, cellulose, alginate, chitosan, collagen, gelatin, and fibrin, poly(vinyl alcohol)(PVA), poly(ethylene glycol) (PEG), poly(caprolactone)(PCL), poly(lactic-co-glycolic acid) (PLGA), and poly(glycerol sebacate) (PGS)".

In healthcare, nanotechnology opens new limits in the life sciences industry. Nanotechnology has great promise in manipulating things at the atomic level to change many parts of medical treatments such as diagnosis, monitoring of diseases, operating equipment, regenerative medicine, developing vaccines, and medication delivery. It also opens the way through sophisticated research instruments to develop drugs for the improvement of treatments for various ailments. According to Haleem et al. (2023), nanotechnology can also be utilized for medication for distinct cells in the body, thereby reducing the risks of failure and rejection.

Also, in the field of medical imaging, nanoparticle fluorescence imaging has been used in gene detection, protein analysis, enzyme activity evaluation, element tracing, cell tracking, early stage disease diagnosis, tumor related research, and monitoring real time therapeutic effects (Han et al., 2019).

Automobile Applications

Due to the need to reduce vehicle weight, which has a direct impact on fuel consumption and exhaust gas emissions, composite materials have become increasingly popular in the automotive industry in recent years. Improvements in mechanical property have resulted in major interest in nanocomposites in various automotive and general/industrial applications. These include potential for utilization as mirror housing on various vehicles types, door handles, engine covers and intake manifolds, as well as timing belt covers. Camargo, Satyanarayana, and Wypych (2009), explained that the automotive sector remained the major application areas of nanocompossites, with remarkable impact because of enhanced functionality like ecology, safety, comfort, etc. They pointed out that light weight automobile bodies made of "metal- or polymer-based nanocomposites

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with suitable reinforcements are reported to exhibit low density and veryhigh strength (e.g. carbon Bucky fibers, with strength of 150 GPa and weight ≈1/5th of steel)".

As materials with exceptional thermal and mechanical characteristics, the use of nanocomposites in the development of automotive components has been shown to increase production rates, improve thermal and environmental stability, reduce weight in the industry, use fewer wear parts, and indirectly lower CO_2 emissions, as well as environmental pollution. Due to their extensive use in drive mechanisms, the inner and outer power train, suspension and brake systems, exhaust systems and catalytic converters, lubricants, tires, and body parts, the automotive industry accounts for the greatest market share of polymeric nanocomposites.

Civil Engineering

In Civil engineering, the application of nanotechnology in concrete is the most widespread with lots of advantages. Due to their potential to provide reinforcement, polymer nanocomposites have been steadily advancing into the construction sector over the past ten years for use in load-bearing applications all over the world. Polymer Nanocomposite (PNC) is gaining popularity among structural and building engineers due to its prospective benefits, which include high specific strength and stiffness, durability, good fatigue performance, variable production, and lower maintenance costs. According to Utsev et al. (2022), nanocomposites are being applied in civil engineering in areas like lighter structures, stronger structural composites, improved properties of cementitious materials, low maintenance, improved heat and sound insulation, improved self-cleaning ability, water repellent ability, glass reflectivity and antifogging surfaces, ultravioletray protection, nanosized sensors for controlling construction sites, as well as other applications.

Applications for PNCs include alternate concrete reinforcement, rehabilitation and retrofit, and, in a few rare instances, whole fiber composite constructions. New-generation Carbon Fiber-Reinforced Polymer (CFRP) composites are the engineer's desired material for PNC applications because of their high thermo-mechanical properties, superior corrosion resistance, robustness, translucency, lightweight, and processing ease. According to Naskar (2017), in CFRP, the reinforcing fiber supports strengthening and stiffening the structure, whereas the matrix links the fibers together and distributes the stress from one fiber to another, thereby providing superior qualities.

Defense/Aerospace Safety

Nanotechnology advancements that are relevant to the defense industry led to improvements in a number of applications, including but not limited to: sensors, smart textiles, and lightweight but durable materials for military ammunition. By improving the performance of weapons and gadgets, nanotechnology promises several uses in defense, particularly in aircraft, sensors, nano-electronics, energy storage, memory storage, nano-robotics, transducers, propellants, and explosives. With the rise of terrorist and illicit activities, there is an increased need for aviation security to discover relatively small quantities of explosives or drugs.

In one step free radical polymerization, Dutta, Chakravarty, and Sarma (2016), disclosed the production of carbon and silver nanoparticles impregnated in graft polymers of poly (vinyl alcohol) and polythiophene for the detection of nitro-aromatic chemicals by fluorescence measurement. The delocalized p-electron density of the luminous polymer was improved by the addition of the conducting nanoparticles. By using the fluorescence quenching approach, the electron-rich nanocomposites are useful for the selective detection of electron-deficient nitroaromatic explosives.

Several other studies have carefully shown other areas of application of nano composites in defence and aerospace industry. Nanotechnology is developing near-flawless materials that can improve performance safety, while lowering aircraft production and maintenance costs. Many structural adhesives and fiber-reinforced composites for aerospace applications can benefit from the addition of silica nanoparticles with a tailored surface in an epoxy resin. Molecular-tuned nanofiller-incorporated resin significantly improves the compressive strength and fatigue behaviour of the fibre-reinforced composite materials prepared with this resin(Singh et al., 2023).

The Ministry of Defence in the UK has predicted that technologies such as medical nanobots and nano-enhanced reconnaissance and communication devices (such as micro-radar for miniature vehicles) will begin to be used from 2030 onwards. Improved body armour is a major focus for military nanotechnology research.

Polymer nanocomposites' qualities make them a suitable material for usage in the aviation sector; these are rapidly being investigated as substitutes for certain metals in aircraft airframes. Nanotechnology advancements using molecular engineering and design concepts have recently aided in the alignment and orientation of nanofillers into the polymeric matrix of super-strong fibers for ballistic armor applications. Developments in weaponry that come with comparable advances in armor and nano-materials could be modified and designed to build powerful armors. The aluminium alloy incorporated with CNTs is explored to make vehicle armor, and Krylon terminator ballistic body armors made from these materials can withstand multiple impacts.

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Nanostructured materials can create durable, lightweight, robust, adaptive armor and nanofibre-based outfits that offers better protection against projectiles. Similarly, the so-called 'smart materials' should be proficient in adapting and adjusting temperature, pressure, light, stresses or hostile pH changes. Recently, efforts are being made to apply nanocomposites for the design and development of suitable battle suits that will be comfortableand lightweight, and simultaneously stop bullets, monitor vital signs, defend the wearer against toxic materials, and also administer first aid when needed.

Food and Agriculture

Nano composites have a wide range of applications in food packaging. They have been widely employed in antimicrobial packaging of food items in recent years. They are primarily used to protect foods from mechanical and high-temperature shock, as well as to extend their shelf life. According to Honarvar et al.(2016) because zinc oxide nanocomposites possess antioxidant properties, it is commonly employed in the active packaging of food items.

Mohammed, Ahmad, and Ibrahim (2022), in their research observed that nanocomposites are being applied in various areas of food, and this ranges from food packaging, food safety, and food processing. Nanotechnology in the food sector serves to improve food safety by detecting diseases and toxins and providing nutritional information. The use of nanotechnology in food packaging may alter how food is packaged. As a result, nanotechnology applications in food packaging are promising since they can improve food quality, safety, and shelf life.

On the other hand, considering agricultural applications, Nanotechnology offers new agro-chemical agents and delivery systems to boost crop production, while reducing pesticide applications. Nanotechnology can boost agricultural production by using nano-formulations of agrochemicals for applying pesticides and fertilizers for crop improvement; nano-sensors in crop protection for identifying diseases and agrochemical residues; and nano-devices for plant genetic engineering; plant disease diagnostics; animal health, animal breeding, poultry production; and postmharvest management.

Precision farming techniques may be used to increase crop yields while minimizing soil and water impact. Furthermore, it can reduce nitrogen loss due to leaching, emissions, and soil microbes.

Electronics/Information Technology

Smartphones and other compact computing devices are made using nanotechnology. The development of nanotechnology in computers is as a result of the desire for more powerful computers with more memory at lower weights and cooler temperatures. Apart from increased computing power, nanotechnology in computers is enabling enhanced memory storage. The "nanodot" with its capacity to condense massive amounts of data into a small space, may ultimately replace the hard drive disk. Although that nanomaterials are often more expensive than silicon materials, rising demand usually overrides economic concerns.

The application of nanotechnology in the electronics sector is very advantageous. Quantum dots for instance, are incredibly tiny light-producing cells that can be used for display screens or lighting. On silicon chips, there are already millions of components. Nevertheless, as technology develops, circuits become so tiny that they will malfunction if a molecule is out of place. Circuits will be able to be accurately constructed at the atomic level, thanks to nanotechnology. These explain why Tyagi and Tyagi (2014), stated that nanotechnology is deeply embedded in the design of advanced devices for electronic and optoelectronic applications, as the utility of polymer-based nanocomposites in these areas is quite diverse involving many potential applications and have been proposedfor their use in various applications.

Environment Remediation

By enabling new and improved ways for monitoring, cleaning up, and reducing environmental pollutants, nanotechnology has the potential to play a key role in environmental protection and sustainability. Several nanoscale materials with environmental applications have been produced in recent years. Nanoscale materials, for example, have been utilized to rehabilitate contaminated soil and groundwater at hazardous waste sites, such as those affected by chlorinated solvents or oil spills. According to Mohamed (2022), for environment remediation, nanocomposites have wide applications in diverse areas like air purification, wastewater treatment via heavy metal removal, soil improvement, fertilizers delivery systems, food packaging and flame retardency. He pointed out that lately nanocomposite structures are employed to purify water, develop fertilizer retention in soil, and enhances plant growth resulting in agricultural development, as well as in food packaging.

In doing this however, it is essential to take into account the potential environmental and health effects of nanotechnology and to put measures in place to mitigate these risks. This includes ensuring that nanotechnology is produced and used responsibly and sustainably, as well as being subject to appropriate regulation and control. Overall, nanotechnology has the potential to improve the environment and sustainability, but its development and deployment must be approached with caution and a commitment to responsible applications.

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V. Conclusion

It has been observed that nanocomposites have set the current trend in the novel materials drawing considerable interest due to the unusual properties they display. Nanocomposites are especially promising for sophisticated niche areas, as they are already being be used in a number of applications; nevertheless, there are still various potential areas where nanocomposites can be utilized in the future.

The following prediction were made by Booker and Boysen (2005), by the year 2012 significant products will be available using nanotechnology (medical applications including cancer therapy and diagnosis, high density computer memory. They pointed out that in 2015 there will be advances in computer processing; by 2020, new materials and composites will emerge and lastly by 2025, there will be significant changes related to energy. These predictions are in no doubt practicable in recent times. The worldwide production for nanocomposites is estimated to exceed 600,000 tonnes and is set to cover the following key areas in the next five to ten years: Drug delivery systems, Anti-corrosion barrier coatings, UV Protection gels, Lubricants and scratch free paint, new fire-retardant materials, new scratch/abrasion resist materials, superior strength fibers, as well as films.

References

1. Amin, M. (2013), “Methods for Preparation of Nano-Composites for Outdoor Insulation Applications” COMSATS Institute of Information Technology Wah, Pakistan
2. Balaji, V., Manasa, B., Aakash, N., Chandrakaanth, B., and Kiran, K. (2017), “Nanocomposites and their Applications” International Journal of Engineering Research in Mechanical and Civil Engineering, vol 2. 1ss. 11
3. Booker, R., and Boysen, E. (2005), “Nanotechnology for Dummies”[Online]. Accessed on 22 May, 2023, from https://docplayer.net/33570658-Nanotechnololgy-for-dummies-by-richard-booker-and-earl-boysen.html
4. Bogue, R. (2011), "Nanocomposites: A Review of Technology and Applications" Assembly Automation, vol. 31, iss. 2
5. Carmago, P., Satyanarayana, K., and Wypych, F. (2009), “Nanocomposites: Synthesis, Structure, Properties and New application Opportunities” Materials Research, vol. 12, iss. 1
6. Din, S., Shah, M., Sheikh, N., and Butt, M. (2019), “Nano-composites and their Applications: A Review” Characterization and Application of Nanomaterials, vol. 2
7. Dutta, P., Chakravarty, S., and Sarma, N. (2016), “Detection of Nitroaromatic Explosives Using π-Electron Rich Luminescent Polymeric Nanocomposites” Royal Society of Chemistry, vol. 6
8. Fawaz, J., and Mittal, V. (2015), “Synthesis of Polymer Nanocomposites: Review of Various Techniques” Wiley-VCH Verlag GmbH and Co. KGaA
9. Haleem, A., Javaid, M., Singh, R.,and Suman, R. (2023), “Applications of nanotechnology in medical field: a brief review” Global Health Journal, vol. 7, iss. 2
10. Han, X., Xu, K., Taratula, O., and Farsad, K. (2019),“Applications of Nanoparticles in Biomedical Imaging” Nanoscale,vol.11, iss. 3
11. Honarvar, Z., Hadian, Z., and Mashayekh, M. (2016), “Nanocomposites in Food Packaging Applications and their Risk Assessment for Health. Electron Physician, vol. , iss. 6
12. Jiang, S., Liu, Z., Jiang, D., Cheng, H., Han, J., and Han, S. (2016), “Graphene as a Nanotemplating Auxiliary on the Polypyrrole Pigment for Anticorrosion Coatings” High Performance Polymers.[Online]. Accessed on 17 July, 2023, from https://doi.org/10.1177/0954008316647469.
13. Jiang, Y., Li, J., Li, B., Liu, H., Li, Z., and Li, L. (2015), Study on a Novel Multifunctional Nanocomposite as Flame Retardant of Leather. Polymer Degradation and Stability. [Online]. Accessed on 23June, 2023, from https://doi.org/10.1016/J.POLYMDEGRADSTAB.2015.02.018.
14. Kherroub, D., Belbachir, M., and Lamouri, S. (2015),“Synthesis of Poly(furfuryl alcohol)/Montmorillonite Nanocomposites by Direct in-situ Polymerization” Bulletin of Materials Science. [Online]. Accessed on 11 July, 2023, from https://doi.org/10.1007/s12034-014-0818-3.
15. Kiron, M. (2021), “Classification, Properties and Applications of Polymer Nanocomposites” [Online]. Accessed on 17 April, 2023, from https://textilelearner.net/nanocomposites-classification-properties/
16. Krishnamoorti, R. and Giannelis, E. (1997), “Rheology of End-Tethered Polymer Layered Silicate Nanocomposites” Macromolecules, vol. 30, iss. 14
17. Kumar, S., and Krishnamoorti, R. (2010), “Nanocomposites: Structure, Phase Behavior, and Properties” Annual Review of Chemical and Biomolecular Engineering, vol. 1
18. Kumari, P., Rao, Y., and Akhila, S. (2019), “Role of Nanocomposites in Drug Delivery” GSC Biological and Pharmaceutical Sciences Journal, vol. 8, iss. (3)

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XII, Issue VIII, August 2023

19. Li, Z., Shan, X., Chen, Z., Gao, N., Zeng, W., Zeng, X., and Mei, L. (2021), "Applications of Surface Modification Technologies in Nanomedicine for Deep Tumor Penetration" Advanced Science, [Online]. Accessed on 8May, 2023, from https://doi.org/10.1002/advs.202002589
20. Liny, P. and Patil, J. (2021), "Nanocomposites – An Overview of Classification and Applications" Journal of Emerging Technologies and Innovative Research, vol. 8, iss. 10
21. Mantia, F., and Dintcheva, N. (2006),"Eva Copolymer-Based Nanocomposites: Rheological Behavior Under Shear and Isothermal and Non-isothermal Elongational Flow" Polymer Testing"[Online]. Accessed on 30 April, 2023, from https://doi.org/10.1016/J.POLYMERTESTING.2006.03.003
22. Mohammed, Z., Ahmad, F., Ibrahim, S. (2022), "Application of Nanotechnology in Different Aspects of the Food Industry" Discovery Food 2, 12 [Online]. Accessed on 28 April, 2023, from (2022). https://doi.org/10.1007/s44187-022-00013-9
23. Muller,K., Bugnicourt, E., Latorre, M., Jorda, M., Sanz, Y., Lagaron, J., Miesbauer, O., Bianchin, A., Hankin, S., Bölz, U., Pérez, G., Jesdinszki, Lindner, M., Scheuerer, Z., Castelló, S., and Schmid, M. (2017), "Journal of Nanomaterials" vol. 7, iss. 74
24. Naskar, M. (2017),"Polymer Nanocomposites for Structure and Construction Applications"[Online]. Accessed on 17 April, 2023, fromhttps://doi.org/10.1007/978-3-662-53517-2_3
25. Occhiutto, M., Maranhão, R., Costa, V. (2020), "Nanotechnology for Medical and Surgical Glaucoma Therapy— A Review"Advanced Therapy 37,[Online]. Accessed on 17 April, 2023, from https://doi.org/10.1007/s12325-019-01163-6
26. Okpala, C. (2013), "Nanocomposites – An Overview" International Journal of Engineering Research and Development, vol. 8, iss. 11
27. Okpala, C. (2014), "The Benefits and Applications of Nanocomposites" International Journal of Advanced Engineering Technology, vol. 5, iss. 4
28. Oliveira, M., and Machado, A. (2013), "Preparation of Polymer-Based Nanocomposites by Different Routes" Institute for Polymers and Composites, Department of Polymer Engineering, University of Minho, Guimarães, Portugal
29. Rajani, A., Chauhan, P. and Dave, P. (2021), "Nanocomposites: A New Tendency of Structure in Nanotechnology and Material Science" Journal of Nanoscience and Technology, vol. 7, iss. 1
30. Saritha, A., Joseph, K., Thomas, S., and Muraleekrishnan, R. (2012), "Chlorobutyl Rubber Nanocomposites as Effective Gas and VOC Barrier Materials" Applied Science and Manufacturing. [Online]. Accessed on 20 April, 2023, fromhttps://doi.org/10.1016/J.COMPOSITESA.2012.01.002.
31. Singh, K., Jaiswa, R., Kumar, R., and Agarwal, K. 2023), "Polymer-Based Nanocomposites as Defence Material" Bulletin of Material Science, vol. 46, iss. 2
32. Thomas, P., Stephen, R., Bandyopadhyay, S., and Thomas, S. (2014), "Polymer nanocomposites: Preparation, Properties and Applications" [Online]. FRP, vol. 2. Accessed on 19 July, 2022, from https://www.researchgate.net/publication/233950668
33. Tyagi M., and Tyagi, D. (2014), "Polymer Nanocomposites and their Applications inElectronics Industry" International Journal of Electronic and Electrical Engineering, vol. 7, iss. 6
34. Usuki A, Kojima Y, Kawasumi M, Okada A, and Fukushima Y. (1993), "Synthesis of Nylon 6-Clay Hybrid" Journal of Materials Research. vol. 8
35. Utsev, T., Tiza, T., Mogbo, O., Singh, S., Charkravarti, A., Shaik, N., and Singh, S. (2022), "Applications of Nanomaterials in Manufacturing" Materials Today: Proceedings, vol. 62, iss. 9
36. Mohanavel, V., Suresh, S., Ravichandran, M., Sivanraju, R., Velmurugan, P., and Subbiah, R.(2022), "Influence of Nanofillers on the Mechanical Characteristics of Natural Fiber Reinforced Polymer Composites"Electrochemical Society Transactions. Vol. 107, iss. 1
37. Zapata, P., Quijada, R., Retuert, J., and Moncada, E. (2008), "Preparation of Nanocomposites by In Situ Polimerization" Journal of the Chilean Chemical Society, March 2008