Cogent Engineering

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/oaen20

Approaches, attributes and applications of matrix nanocomposites – a review

M. Rajamehala, C.K Phiri & Vijay Pradhap Singh M

To cite this article: M. Rajamehala, C.K Phiri & Vijay Pradhap Singh M (2022) Approaches, attributes and applications of matrix nanocomposites – a review, Cogent Engineering, 9:1, 2152650, DOI: 10.1080/23311916.2022.2152650

To link to this article: https://doi.org/10.1080/23311916.2022.2152650

© 2022 The Author(s). This open access article is distributed under a Creative Commons Attribution (CC-BY) 4.0 license.

Published online: 10 Dec 2022.

Submit your article to this journal

Article views: 600

View related articles

View Crossmark data

Citing articles: 1 View citing articles

Full Terms & Conditions of access and use can be found at
https://www.tandfonline.com/action/journalInformation?journalCode=oaen20

M. Rajamehala et al., *Cogent Engineering* (2022), 9: 2152650
https://doi.org/10.1080/23311916.2022.2152650

cogent engineering

MATERIALS ENGINEERING | REVIEW ARTICLE

Approaches, attributes and applications of matrix nanocomposites – a review

M. Rajamehala[1]*, C.K Phiri[1] and Vijay Pradhap Singh M[2]

Received: 31 August 2022
Accepted: 24 November 2022

*Corresponding author: M. Rajamehala, Department of Education, DMI-St. John The Baptist University, Mangochi, Malawi
E-mail: rajamehala@gmail.com

Reviewing editor:
Ian Philip Jones Jones, Metallurgy & Materials, The University of Birmingham, United Kingdom

Additional information is available at the end of the article

Abstract: Nanocomposites, a high-performance material, showcase uncommon asset combos and precise layout possibilities. Their versatility is so compelling that they can be of use in many countries, spanning from packaging to medical purposes. In this comprehensive evaluation, the three varieties of matrix nanocomposites are presented, demonstrating the use of such compounds, their optimization techniques, and a few latest consequences on structure, parameters, and potential programs. The parameters of nanoparticles are rapidly changing in accordance with their grain size equivalents. Furthermore, it modifies the manner in which molecules are hooked up to grain materials. As a consequence, the materials are often changed repeatedly with respect to the elements. A few other nanocomposite products have been shown to be 1,000 times tougher than most of the elements. This is necessary to understand the existence and usage of nanocomposite substances and examine components, functions, and innovative attributes in polymer, ceramic, and metallic nanocomposites. It is deduced by taking a quick glance at technological and biochemical applications. It can be seen that polymer nanocomposites and eventually the chemicals are used mostly in their processing and find applications in various industries, including aviation, the defense industry, food, and electronic components, attributable to their heavier mechanical, electrical, and thermal properties. This chapter forms the basis for and takes an approach to the emerging field of nanocomposite technology as it relates to biofuel production and its implementation.

Subjects: Materials Chemistry; Materials Science; Nanobiotechnology

Keywords: Nanocomposites; nanomaterials; polymer; bulk material; dispersion

1. Introduction

Dimensionality is a very common factor in determining the properties of matter. The nanostructure of a fabric is the key figure in the advancement of novel properties and in controlling the structure at the nanolevel. Nanotechnology is consequently a promising field of the twenty-first century (Bayda et al., 2020; Wennersten et al., 2008). This is completely anticipated to restructure the innovative applications in the areas of semiconductors, inorganic, as well as natural materials, vitality capacity and biotechnology. The term "nanotechnology" can be characterized as the control of materials with at least one measurement less than 100 nm (Babick et al., 2016; European Commission, 2011). This innovation endeavours to integrate chemistry, material science and science to make modern fabric properties that can be tainted to create effortless forms for the generation of electronic gadgets and biomedical items. Recent advances in metal synthesis include a wide range of physical and chemical strategies that have significantly affected the field of nanomaterials (Karthiga et al., 2019). The commercialization of nanotechnology is

cogent oa

© 2022 The Author(s). This open access article is distributed under a Creative Commons Attribution (CC-BY) 4.0 license.

anticipated to boost wide-ranging mechanical improvements, progress in quality of life, and societal benefits around the world. Nanocomposites are materials that are composed of two or more constituents with diverse physical and chemical properties. Such materials stay unique and definite at the infinitesimal level but collectively contain a single physical fabric with a measurement of less than 100 nm (Guo et al., 2007). These substances are section structures that encompass a polymeric matrix and dispersed inorganic particles of nanometre scale. The maximum inorganic particles belong to the circle of relatives known as 2:1 phyllosilicate (Sinha et al., 2003). The comfortable and practical magnificence of synthetic/inorganic substances in nanocomposites tends to be a highly integrated line of research. Substantial effort is usually based on the competence by progressive technological interventions to regain control of nanostructures. In addition, the parameters of nanocomposite materials rely on their morphological traits and interfacial characteristics. With novel elements, this promptly expanding field develops many exciting new products. All of these can generate into any other metal straightaway, by incorporating characteristics from the parent resources. Recent structures that are often unfamiliar inside the interpreted additive materials are also feasible. Now, nanocomposites can be defined as nanomaterials that integrate one or more separate additives so that you can gain the high-quality properties of every issue. These nanocomposites have- stepped forward residences whilst as compared to the character issue materials by means of synergetic impact of both the person additives.

Nanocomposites recommend uncommon properties that rise from their little size, huge surface zone and the relations of stages at their interfaces. It has been accounted that those deviations in molecule properties can be seen when the molecule size is less than a specific level, which is called as “the basic size” (Choa et al., 2003; Wypych et al., 1997).

Almost all of the interactions at stage interfaces are strengthened, when dimensions appear at the degree of nanometres. In addition, the expose of carbon nanotubes and perhaps their advanced use made to figure out the composites exhibiting a substantial part of the remarkable carbon nanotubes involved in dealing with conventional and thermal characteristics that applied another and instructive estimation to the above region. Nanocomposites are currently offering a technological breakthrough and picking things up for all fields as well as being environmentally sound (Aruna et al., 2003; Giannelis, 1996; Sternitzke, 1997).

These nanocomposites are of various kinds chiefly based on the primary element (compositionally more quantities) in which the continuous segment is referred to as matrix and the filler factor (compositionally less quantity) as dispersed segment. They are (a) inorganic in inorganic (metal nanocomposites consisting of Ag/TiO_2, $SiO_2/CdTe$ and many others), (b) natural in natural (dendrimers, graphene/polymer) and (c) natural in inorganic or inorganic in natural composites (polymer nanocomposites) (Koo, 2006; Schadler, 2003). They are indeed the components of the 21st century in consideration with their specific design and developmental combinations that are not really found in conventional composites. The desired conception of certain variables has not been met yet (Schmidt et al., 2002). Although the first reference to them had been reported in 1992 (Gleiter, 1992).

Nanocomposites offer an exceedingly huge variety of prospective programs from electronics, optical communications, agriculture, medicinal and organic systems to new materials (Mahmood et al., 2022). Many possible packages had been explored and lots of gadgets and structures have been considered. More ability programs and new devices are being proposed. It is evidently impossible to recapitulate all of the devices and applications which have been studied. It is intriguing to take note that the utilizations of nanocomposites in various fields have obviously various demands, and besides, these lines face various difficulties, which require various methodologies (Alexandre & Dubois, 2000; Gangopadhyay & Amitabha, 2000; Peigney et al., 2006). In agriculture pest control, in tea plantation, nanopesticides enters only into target pests while remaining steady and active in the environment. This embraces environmentally friendly scenario as the nano novel pesticides

formulation does not affect non-target and uses cost-effective formulation (Benelli, 2016; Smith et al., 2008). Furthermore, nanoparticles are considered as ultrafine particles composed of dimensions ranging from 1 to 100 nm in size but having different traits in comparison with the non-nanoparticles with the same chemical composition (Auffan et al., 2009).

2. Types and processing of matrix nanocomposites

Nanocomposites can be classified into three groups in terms of their matrices (Hafeez, 2022) which include:

(1) Ceramic Matrix Nanocomposites
(2) Metal Matrix Nanocomposites
(3) Polymer Matrix Nanocomposites

2.1. Ceramic matrix nanocomposites

Ceramic matrix nanocomposites (CMNCs) have Al_2O_3 or SiC device in particular (Xiao et al., 2009). Most research referred here revealed the substantial reshaping of the Al_2O_3 matrix following the addition of a low compression of SiC debris of equivalent size and dry squeezing of the ensuing combination.

The most used methodologies for the preparation of CMNCs are traditional powder technique; composite substrate direction; solvent carburizing; vapor techniques and molecular techniques that include sol–gel phase, deposition strategies and prototype formulation. Ceramics are typically brittle as well as broken because of split dissemination. Ceramics are made feasible for industrial purposes by adding a highly conductive metallic layer or some other compound in the mixture. This ends in conventional characteristics, inclusive of compressive strength and dislocation durability, resulting from the interaction among the distinct levels, matrix and reinforcements, at the stage constraints (Liu et al., 2004; Thompson et al., 2003).

2.1.1. Ceramic nanocomposite reinforcement structures with discontinuous matrices

The nanocomposite's efficiency is massively improved as opposed to its micro-equivalent. Due to the strengthened supramolecular connection between the molecules in nanocomposites, the fracture power is distinctly improved. Except that Al_2O_3, 5–15% SiC systems exhibited 200 MPa plastic deformation grooves on the surface. However, Si_3N_4 fails at 0.3% strain after 0.4 hours, while Si_3N_4/10% SiC nanocomposite fails at 1.5% pressure even after 1,000 hours. Morphological analysi and microstructures of a few acrylic membrane nanocomposites of Al_2O_3 and Fe_2O_3 contains an amazing allocation of cobalt and nickel nanoparticles (Ogawa & Kuroda, 1997; Shah et al., 2016).

2.1.2. Ceramic matrix-carbon nanotube structures

Whilst the quantity of carbon nanotubes is lower than 5% in volume, contracting electricity and crack longevity grow with the extent of carbon nanotubes. The improvement in structural properties is due to the huge component proportion and magnificent mechanical parameters of carbon nanotubes, in line with the principle of short-term fibre-reinforced composites (Borsa et al., 1995; Kojima et al., 1993; Stearns et al., 1992). The less in bending energy at high loading is because of the difficulty, which is resulting from carbon nanotubes at higher density, as they show an increased opportunity of aggregation. In addition, in Al_2O_3/nanotube composites, uncommon behaviours with excessive interaction-damage friction without the need for a significant increase in durability were mentioned. When the quantity of carbon nanotube is raised above 4% in weight, the microhardness of certain materials elevates. It might be due to grain length as a result and the rigid function of carbon nanotubes (Din et al., 2016; Riedel et al., 1989).

Formation of SiC/carbon nanotubes confirmed 10% increase in electricity and rupture longevity related to homogeneous materials. As a result, several other attempts have been made to improve

tensile strength by incorporating carbon nanotubes in ceramic matrices. Moreover, the detected enhancements have been no longer as excessive as predicted. Single-walled carbon nanotubes used to strengthen ceramic polymers through spur-plasma laser welding resulted in rising of fracture toughness over natural aluminium oxide. A 24% increase in fracture sturdiness above the matrix was found in nanograined Al_2O_3 composite containing 10-volume percentage multi-walled carbon nanotubes, which changed to attribute the oxidation of carbon nanotubes earlier than diffusion. In such a situation, the substance was transformed under three circumstances, i.e. combined, warm squeezed (1573 K) and plastic resin close to conceptual mass (Hench et al., 1990; Vorotilov et al., 1999).

2.2. Metal matrix nanocomposites

Metal matrix nanocomposites (MMNCs) check with a tensile material or alloy matrix where a few nanosized strengthening components are embedded. Such substances incorporate the qualities of steel and ceramic. Metallic matrix composites such as aluminium and magnesium are fortified with continuous carbon. SiC or boron fibres are used in aerospace and various programs due to their relative mass and incredible natural processes. There have been plenty of opportunities to create comparable composites, including nanoparticles and CNTs for structural projects, as these substances always have the capacity to generate more improvements than micron-sized enhancements. Steel matrix nanocomposites have been researched for about 10 years, but it remains at an early stage. The remaining goal is to extend the advanced materials for use in the military, aviation and automobile industries; however, as with their numbers of ceramics and polymers, manufacturing techniques critically control the residence of a nanocomposite steel matrix (Bogue, 2011).

The invention of recent alloys has been escorted with the aid of predominant developments. Mixing copper andtin resulted in a metal that was one mile stronger than copper, which led to the discovery of bronze. Whatever the techniques of synthesis, most nanocrystalline materials are primarily based on metallic–metallic nanocomposites that show off an incredible resistance to grain boom. Thermal stability and the mechanisms concerned in nanocrystalline materials are not handiest associated with the microstructural and compositional parameters; however, additionally it is associated with porosity, impurity, grain size distribution, texture and microstrain that resulted during the processing of nanocrystalline materials. The simple blending of exclusive metal nanocomposites will transpire with new attributes. Nanocomposite structures along with carbon nanotubes have been drastically studied. There was a non-stop growth in the variety of courses at the concern, including reviews from time to time. Exclusively in the case of PMNC, the views cope with processing factors, such as layered silicates, accomplishing and biodegradable polymer-primarily based systems, fibre bolstered and structure, morphology and belongings aspects along with the uses and outlooks, such as key scope and disputes the growth of structural and functional fibre nanocomposites (Kundu et al., 1998; Sen et al., 2004; Viart et al., 2003).

The techniques used for the processing of MMNCs are spray pyrolysis; liquid metal infiltration; speedy solidification; vapour techniques; electrodeposition and chemical strategies, which consist of colloidal and sol–gel processes (Rajamehala et al., 2022). Fe-based nanocomposites are organized by using solidification techniques. Branagan stresses about the “devitrified nanocomposite steel”. The development of nanophases, with the help of excessive crystallization intensity, was established in a short period for the emergence of particles that are greater than the impingement. The use of ultrasound has actually improved the wettability between the matrix and the debris (Ananthakumar et al., 2004; Baiju et al., 2005).

2.3. Polymer matrix nanocomposites

Polymer matrix nanocomposites (PMNCs) are commonly involved in technology to ease the processing, for its lightweight and ductile purposes. The reinforcing substances engaged inside the fabrication of polymer nanocomposites can be labelled in line with their dimensions. Sources include round silica, metallic particles and superconducting nanoclusters. Nanotubes or whiskers, viz. measurements on a nanometre scale, provide the particular type of strengthening which

results in the development of a prolonged shape (Berger, 2004; Stankovich & Mater, 2006; Zhang et al., 2005). A single dimension in the nanometre range defines the third type of enhancement. On this organization, the filler carries panels from one to several nanometres of thickness. This specific family is referred to as polymer-layered nanocomposites. Many artificial and herbal crystalline hosts, which can be in a position, under precise situations, to intercalate a component, have been identified. Examples consist of graphite, metallic chalcogenides, clays, layered silicate and layered double hydroxides (Chung et al., 2004; Ounaies et al., 2003).

3. Key attributes of nanocomposites

The unique natures of nanocomposite filler particles offer mechanical strength and abrasion resistance comparable to hybrid composites, as well as superior shine and gloss durability compared to microfill composites.

3.1. Polymerization shrinkage

The composite resin polymerization shrinkage is estimated to be 1.4–1.6%. Due to its low epoxy resin shrinkage and strong intermolecular correlations between tar and nanomaterials, the performance of nanocomposites is low. The volumetric reduction relies on the total content of the composite organic matrix. Fortin and Vargas (2000) reported that nanohybrid composites showed less organic matrix and less shrinkage (13.0 wt%). A low-shrinkage, light, treatable dental nanocomposite was set up by utilizing an epoxy sap 3,4-epoxycyclohexylmethyl-(3,5-epoxy) cyclohexane carboxylate network with 55 wt% of 70–100 nm nanosilica fillers through ring opening polymerization. γ-Glycidoxypropyl trimethoxysilane was utilized to modify the surfaces of silica nanoparticles. The created epoxy tar-based nanocomposite showed low shrinkage and high quality and is reasonable for dental remedial material applications (M Chen et al., 2006).

3.2. Water sorption

Water used in the polymeric period of composites usually causes two contradicting forms. The dissolvable will separate unreacted parts, principally monomer, bringing about shrinkage, loss of weight and decrease in mechanical properties. Alternately, dissolvable take-up prompts a growing of the composite and increment in weight. The dissolving agent diffuses into the polymer system and isolates the chains making expansion (Ortengren et al., 2001).

However, since the polymer matrix contains micro-voids made during polymerization and free volume between chains, a piece of the dissolving agent is obliged without making an adjustment in volume. In this manner, the dimensional difference in a polymer composite in a solvent is mind boggling and hard to anticipate and relies upon the substance structure of the polymer lattice. Overall, nanohybrid composites show less water sorption than nanofill composites. Water used in the polymeric period of composites causes two contradicting forms. The dissolvable concentrates unreacted parts, essentially monomer, bringing about shrinkage, loss of weight and decrease in mechanical properties. The dissolving agent diffuses into the polymer system and isolates the chains making development (Ortengren et al., 2001). Since the polymer contains microvoids made during polymerization and free volume between chains, a piece of the dissolvable is suited without making an adjustment in volume. Along these lines, the dimensional difference in a polymer composite in a dissolvable is intricate and hard to anticipate and relies upon the concoction structure of the polymer framework.

Mayworm et al. (2008) found that the wear opposition of nanoparticles containing dental composites increments after its stockpiling in counterfeit spit. The capacity of fake spit expands the material's wear obstruction, meaning that material building post-fix happens and salivation retention happens just on the outside of the composites. Surface microhardness of the composites diminishes after the capacity in fake salivation while mass microhardness of the materials builds (Mayworm et al., 2008). Moreover, it has been accounted for that radiopaque Ta_2O_5/SiO_2 filler nanoparticles scattered in a methacrylic framework bring about glues with radio capacity higher than dentin and polish and superb cement strength (Schulz et al., 2008).

3.3. Flexural quality

The flexural quality relies upon the filler content and the filler science. The flexural consistency of nanocomposites was considered to be measurably similar or stronger than that of crossbreed or microhybrid composites and fundamentally larger than other composites. Nanofill composites, which have higher filler stacking, show more noteworthy flexural quality than nanohybrid composites, which have lesser filler loading (Lohbauer et al., 2006). Tanimoto et al. (2006) watched dynamic decline in flexural quality as the mean filler-molecule breadth expanded. This examination was constrained to silica fillers from 3.3 to 15.5 μm—significantly over the extreme scope of nanohybrids or nanofills molecule size (Tanimoto et al., 2006). When all substances tested, they exhibited comparable flexural strengths, microfills confirmed the poorest physical characters (Beun et al., 2007).

To improve the mechanical properties of gum-based composites, Xia et al. (2008) utilized TiO_2 nanoparticles treated with the organosilaneallytriethoxysilane (ATES). TiO_2 nanoparticles were sonically scattered in an ethanol arrangement containing ATES. The altered particles were washed in unadulterated ethanol and dried before it was utilized as filler. Spatulation of TiO_2 particles was physically mixed with a gum monomer comprising the most part of UDMA. The particles were then physically added to Z100 dental composite and the blend was mixed. Surface change by the organosilane ATES impacts the scattering and linkage of TiO_2 nanoparticles was inside a tar framework and the altered particles were found to improve the microhardness and flexural quality of dental composites (Xia et al., 2008).

3.4. Wear and gloss retention

The nanosized essential particles in the nanoclusters wear by severing singular essential particles instead of culling out the bigger auxiliary particles from the gum. Therefore, ensuing wear surfaces have smaller cracks and greater maintenance of gloss. Hybrid fillers normally are massive dense debris of a mean size of about 1 μm. Micro-hybrids are identical and considerably lighter than hybrids in the typical molecule width (Palaniappan et al., 2009).

Wear resistance is the most essential physical properties of denture teeth. Porcelain denture enamel has maximum wear resistance; however, they may be brittle, lack bonding to the denture base and hard to shine. Acrylic resin denture enamel is less and difficult to raconteur; however it goes through excessive put on. Nanocomposite denture tooth accommodates of polymethylmethacrylate, and uniformly dispersed nano-sized filler particles. Their advantages are as follows: tremendously polishable, stain- and effect-resistant material, active floor structure, advanced surface hardness and put-on resistance (Chandki et al., 2012).

4. Applications matrix nanocomposites

The number of uses of nanocomposites has been increasing at a faster rate (Hafeez, 2022). The global production is anticipated to exceed 600,000 tonnes and is about to cover the subsequent key regions in the subsequent 5 to 10 years: The nanocomposites market was projected to grow from USD 4.1 billion in 2019 to USD 8.5 billion, by 2024, at a CAGR of 16.0% (Markets and Markets Research Private Ltd, 2019). The market is growing due to the high demand for gas boundaries, oxygen boundaries, nourishment packaging, fuel tanks, films, environmental security and flammability decrease.

4.1. Fuel cells

Usage of fuel cells includes polymers within the proton exchange membrane, electrode binder and bipolar plate matrix. The electrode usually has carbon black debris (0.5–1.0 mm) with 2–5 nm catalyst particles and a polymeric binder (usually Nafion). When platinum nanoparticles are disbursed with Nafion as a binder on carbon nanotubes, it is observed that they stepped-forward reliability over traditional black carbon-based membranes (Kuila et al., 2009). Additionally, the assimilation of nanostructures in and out of the proton alternative molecule has been assessed in

order to boost technical properties and rearrange the tensile strength of protons. Recently, nanotubes were discovered in direct methanol fuel cells. (DeLuca et al., 2006).

4.2. Environmental applications

Due to industrialization, arrival of substantial metallic particles and constant characteristic contamination into the water sources has raised as worldwide issues (Bashir et al., 2020). Substantial steel particles cannot debase into guiltless stop product and reason lethality. With the goal that one could expel overwhelming steel particles from wastewater, a wide scope of techniques are investigated. They are particle trade, substance precipitation, adsorption, film filtration and electrochemical cure (Naushad et al., 2016; Sharma et al., 2017). However, a number of those strategies have consequences such as removal of lingering steel ooze or over-the-top expense (Keng et al., 2014; Mittal et al., 2016). The sullied water from texture, paper and calfskin based earthenware, beautifying agents, ink and nourishment-handling enterprises is unsafe for human presence and consumption. To push off natural colours from this contaminated emanating of businesses, various procedures are accessible. Due to unnecessary effectiveness, low vitality admission and slight reaction circumstances, the photocatalytic approach turns into the focused activity of scientific networks (Ayekoe et al., 2016).

Catalysts mainly used in photocatalysis are titanium dioxide, cadmium sulphide, zinc sulphide, zinc oxide, copper sulphide and iron oxide, which have overpotential in wastewater industry (Kumar et al., 2017b). However, such nanoparticles have a few disadvantages, for example, non-reusability, difficult to take care and accumulation due to their small size. As a result of these inconsistencies, composite catalysts are presented. Composite catalysts might be made with the guide of presenting carbon nanotubes, progress metals, non-metals doping, coloured sensitizers and polymers. Expansion of carbon texture into titanium dioxide supplements the photocatalytic enthusiasm of nanocomposite for wastewater treatment, because of the reality, the carbon drives about as electron sinker and frustrates value supplier. The improvements of catalytic premium and structural strength at broad range of materials were also researched. Models that were derived are mesoporous dirts, agar and polymeric sorbents (Li et al., 2016).

4.2.1. Biofuels

The usage of nanocomposites gains an increase in momentum of biofuel production tactics because of their upgrade results and the biochemical reactions of those bioprocesses as illustrated earlier. Numerous nanocrystals like nanofibers, nanotubes (Ramsurn & Gupta, 2013). earnt the consequences of zero-valent iron (ZVI) metal oxides on biogas generation, utilizing waste actuated ooze at mesophilic circumstances (37°C) (Su et al., 2013). Future energy supply is huge and vast majority of the energy is generated from fossil resources (Bharathiraja et al., 2018). A few researches were performed likewise to break down the outcomes of nanoparticles on microbial networks over the span of anaerobic assimilation methods. H. Wang et al. (2015) assessed the effect of multiple nanoparticles that delegate (ZVI, Ag, Fe_2O_3 and MgO) on biogas fabrication utilizing waste-initiated slime (T. Wang et al., 2016). Biogas generation was hindered by strong groupings of nanoparticles at 15–120 mg/L for CuO and 120–240 mg/L for ZnO, individually. t Fe_3O_4 and ZVI nanoparticles found to be reasonable for the assimilation of effluent, resulting in high biogas output (Abdelsalam et al., 2017). Analysts established that the shape and large execution of that miscellaneous item is extraordinarily reliant on the methodology of amalgamation. Stoeva et al. (2005) suggested a creative strategy through blending of plastic-attractive nanoparticles with the utilization of gold, silica centre and attractive inward layer.

The utilization of nanoparticles in anaerobic processing strategies furthermore gives a harmonious dating as it licenses microorganisms to drive about reactant vendors, whereby they could modify the oxidation realm of the nanoparticle factors. This advances the exchange of electrons and thus allows various responses to happen (Brar et al., 2010; Min & Yoo, 2014). Utilization of nanoparticles has developed as a particular innovation that can be utilized to obtain extreme outputs in development of biodiesel (Y. Chen et al., 2018). It has been shown that the fuse

of nanoparticles through the transesterification process increases the efficacy of the reactants. Y. Chen et al. (2018) assessed the after-effects of Fe_3O_4/ZnMg (Al) O attractive nanoparticles in biodiesel production using microalgal oil (Y. Chen et al., 2018). This impetus showed awesome attractive sensitivity and a massive top layer-to-volume-proportion, which required the assembling of biodiesel, and finished in high return of 94%. Various researches investigated the outcomes of corrosive/base-functionalized nanoparticles on biodiesel production utilizing one of the feedstock. Wang et al. (2017) effectively utilized corrosive functionalized attractive nanoparticles as an impetus for biodiesel creation. The corrosive solubilized nanoparticles, which included sulfamic and sulfonic silica-covered crystalline Fe/Fe_3O_4 center/shell appealing nanoparticles (MNPs), were combined and then used in the transesterification of glyceryl trioleate. Those parts affirmed exorbitant reactant intrigue; however, sulfamic MNPs created a higher synergist movement over the top of biodiesel transformation which is more prominent than 95% (Wang et al., 2017).

4.2.2. Medicinal application

Nanoparticles with large atomic nuclei facilitate a perfect contrast agent during X-ray imaging (Lusic & Grinstaff, 2013). Nanocomposites play a role in the diagnosis of various diseases when patients undergo X-diagnosis (Figure 1). On the other hand, superparamagnetic nanoparticles, for example, those made of iron oxide, are utilized as MRI contrast agents (Babes et al., 1999). In addition, nanocomposite hydrogen is produced as local drug delivery device especially for the management of periodontal infections, and composites in use include nanoparticles, matrix gel and a suitable antibacterial drugs (Kapoor et al., 2015). Nanoparticles used in drugs, proteins and enzymes as entraps prevent denaturation at physiological pH and temperature. As a result, drugs neither swell nor change in porosity (Orive et al., 2005). In summary, nanocomposite has a broader application in the scope of biomedical which includes tissue engineering and drug delivery. The nanocomposites are appropriate substitute to surmount confines such as monolithic and micro-composites, and they are effective in developing multifunctional materials with superior properties such as drugs (Kapoor et al., 2015). Some of the unique properties of nanocomposites in medicine include better healing over fractured bones surfaces, light weight and high strength-to-weight ratio. Furthermore, metal-based nanocomposite materials are made up of alloy or metals in matrix phase which are incorporated with nanomaterial in reinforcement phase. This type is considered as favourable raw material when producing bio-implants which has a unique mechanical property. Nanomaterials are classified as discontinuous or continuous nanomaterial reinforced based on their structure. Continuous reinforced nanocomposites consist of tube-, and rod-shaped nanomaterial in reinforcement phase. Carbon-nanotube-reinforced metal-based carbon nanocomposites are considered due to better tensile strength when used for medical implants. Interestingly, biocompatibility and mechanical strength of magnesium-based metal and alloys are far much better than human bones (Xiong et al., 2017).

4.2.3. Application in agriculture

Nanotechnology is one of the vital innovations which has the potential in improving agricultural productivity through nanofertilizer, efficient herbicides, pesticides, waste management and pathogen detection. Nanotechnology has potentially reduced the doses of applied agrochemicals which enhance biodiversity in the environment (Iavicoli et al., 2017). Furthermore, nanomaterials manage to reduce the loss of nutrients in the soil as compared to conversional approach which negatively affects environment (Figure 2).

In Egypt, a company produces fungicides and growth stimulants through normal methods and has introduced nanotechnology as one way of enhancing the agriculture scope. Specifically, Saula® and vitro NPK are the two nanomaterials aimed to improve utilisation of nutrients supplied by N, P and K compounds as well as supplements such as iron, manganese, zinc, organic acids boron and amino acids (Menossi et al. (2022). Interestingly, nanotechnology has shown to influence germination of seeds as it influences absorption and utilization of water (Abou-Zeid et al., 2021). Furthermore, it improves seed germination as it has the ability to penetrate the seed coat which stimulates enzyme system. Nanopesticide research is the introduction of nanotechnology to protect crops. This uses NPs

Figure 1. Some applications of nanocomposite in biomedical field.

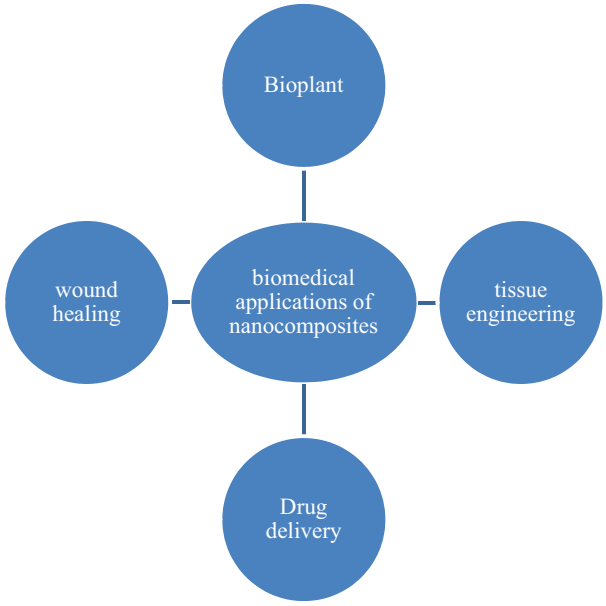
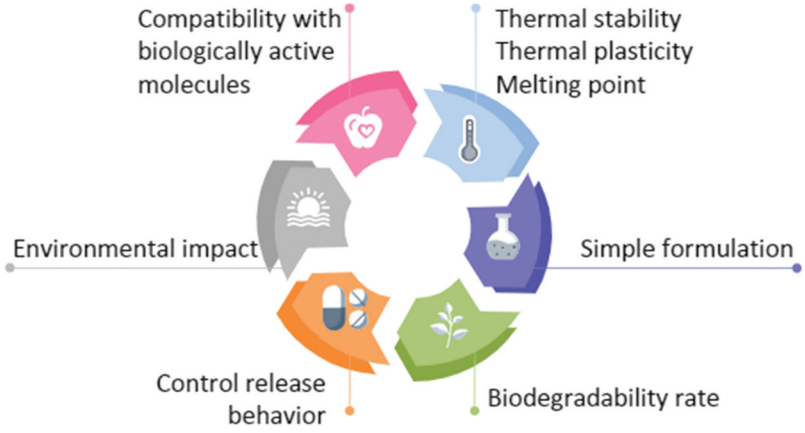


Figure 2. Advantages of biopolymers into agro-nanotechnology.

Source: (Menossi et al. (2022)



which have a diverse fashion and chemical make-up which are metals, metal oxides ceramics, silicates, lipids, polymers, proteins, semiconductor quantum dots (QDs), carbon, dendrimers and emulsions (Niemeyer & Doz, 2001; Oskam, 2006). NP-based pesticide formulations are unique in such a way that their solubility in water is enhanced, formulation stability is elevated, and high mobility and insecticidal activity are attributed to nanosize. On the other hand, formation of nanobio-pesticides, the biological compounds having pesticidal properties, serves as capping and reducing agents and is blended with silver salt (Lade et al., 2017). Biologically synthesized NPs differ from chemically synthesized NPs in terms of their activities and effects on insect pests and plants. Even though the nanopesticides are gaining more attention, they are hampered by the following challenges and issues: bio-efficacy, toxicity to animals, toxicity to plants and toxicity to non-target organisms in agro-ecosystems.

5. Conclusion

Nanocomposites, with its array of properties and unique characteristics, lead to new area of conducting various research initiatives in agriculture, medicine, automobile and environment. The enhanced potential and functions of materials in nanoscale dimensions support the broad-range use of these nanomaterials. The derivation factor from macrosized particles is that it shows adaptive strategies based on size, structure and other parameters. These unique factors govern

the potential use of these materials in various applications like electronics, medical, food and waste management strategies. Nanopesticides in agriculture are gaining more attention as they deal with target pests compared to normal pesticides with a similar structure. The present era is looking for quick and eco-friendly methodologies for making the living easier and cautious process in the waste disposal and management. Thus, these materials with vast applicability natives provide and determine results in aiding technology advancements as well as good scrubbers of waste. Hence, the exploration in the field of nanomaterials production and elucidating its applications will be the major area of research and importance in the coming years.

Author details
M. Rajamehala[1]
E-mail: rajamehala@gmail.com
ORCID ID: http://orcid.org/0000-0003-4404-6943
C.K Phiri[1]
Vijay Pradhap Singh M[2]
ORCID ID: http://orcid.org/0000-0002-7883-9055
[1] Department of Education, DMI-St. John The Baptist University, Mangochi, Malawi.
[2] Department of Biotechnology, Vivekanandha College of Engineering for Women, Namakkal, India.

Disclosure statement
No potential conflict of interest was reported by the author(s).

Citation information
Cite this article as: Approaches, attributes and applications of matrix nanocomposites – a review, M. Rajamehala, C.K Phiri & Vijay Pradhap Singh M, *Cogent Engineering* (2022), 9: 2152650.

References

Abdelsalam, E., Samer, M., Attia, Y. A., Abdel-Hadi, M. A., Hassan, H. E., & Badr, Y. (2017). Influence of zero valent iron nanoparticles and magnetic iron oxide nanoparticles on biogas and methane production from anaerobic digestion of manure. *Energy*, *120*, 842–853. https://doi.org/10.1111/bju.13960

Abou-Zeid, H. M., Ismail, G. S. M., & Abdel-Latif, S. A. (2021). Influence of seed priming with ZnO nanoparticles on the salt-induced damages in wheat (*Triticum aestivum* L.) plants. *Journal of Plant Nutrition*, *44*(5), 629–643. https://doi.org/10.1080/01904167.2020.184928

Alexandre, M., & Dubois, P. (2000). Polymer-layered silicate nanocomposites: preparation, properties and uses of a new class of materials. *Materials Science & Engineering*, *28*(1–2), 1–63. https://doi.org/10.1016/S0927-796X(00)00012-7

Ananthakumar, S., Prabhakaran, A., Hareesh, K., & U, S. (2004). Gel casting process for Al_2O_3-SiC nanocomposites and its creep characteristics. *Materials Chemistry and Physics*, *85*(1), 151–157. https://doi.org/10.1016/j.matchemphys.2003.12.022

Aruna, S., Rajam, T., & K, S. (2003). Synthesis, characterisation and properties of Ni/PSZ and Ni/YSZ nanocomposites. *ScriptaMaterialia*, *48*(5), 507–512. https://doi.org/10.1016/S1359-6462(02)00498-0

Auffan, M., Rose, J., Bottero, J. Y., Lowry, G. V., Jolivet, J. P., & Wiesner, M. R. (2009). Towards a definition of inorganic nanoparticles from an environmental, health and safety perspective. *Nature Nanotechnology*, *4*(10), 634–641. https://doi.org/10.1038/nnano.2009.242

Ayekoe, P., Robert, Y., Goné, D., & D, L. (2016). Preparation of effective TiO_2/ Bi_2O_3 photocatalysts for water treatment. *Environmental Chemistry Letters*, *14*(3), 387–393. https://doi.org/10.1007/s10311-016-0565-3

Babes, L., Denizot, B., Tanguy, G., Le Jeune, J. J., & Jallet, P. (1999). Synthesis of iron oxide nanoparticles used as MRI contrast agents: A parametric study. *Journal of Colloid and Interface Science*, *212*(2), 474–482. https://doi.org/10.1006/jcis.1998.6053

Babick, F., Mielke, J., Wohlleben, W., Weigel, S., & Hodoroaba, V. (2016). How reliably can a material be classified as a nanomaterial? Available particle-sizing techniques at work. *Journal of Nanoparticle Research*, *18*(6), 158. https://doi.org/10.1007/s11051-016-3461-7

Baiju, K., Sibu, C. P., Rajesh, K., Pillai, P. K., Mukundan, P., Warrier, K. G. K., & Wunderlich, W. (2005). An aqueous sol-gel route to synthesize nanosizedlanthana doped titania having an increased anatase phase stability for photocatalytic application. *Materials Chemistry and Physics*, *90*(1), 123–127. https://doi.org/10.1016/j.matchemphys.2004.10.024

Bashir, I., Lone, F. A., Bhat, R. A., Mir, S. A., Dar, Z. A., & Dar, S. A. (2020). Concerns and threats of contamination on aquatic ecosystems. In K. Hakeem, R. Bhat, & H. Qadri. (Eds.), *Bioremediation and biotechnology* (pp. 1-26). Springer. https://doi.org/10.1007/978-3-030-35691-0_1

Bayda, S., Adeel, M., Tuccinardi, T., Cordani, M., & Rizzolio, F. (2020). The history of nanoscience and nanotechnology: From chemical–physical applications to nanomedicine. *Molecules*, *25*(1), 112. https://doi.org/10.3390/molecules25010112

Benelli, G. (2016). Plant-mediated biosynthesis of nanoparticles as an emerging tool against mosquitoes of medical and veterinary importance: A review. *Parasitology Research*, *115*(1), 23–34. https://doi.org/10.1007/s00436-015-4800-9

Berger, C. (2004). Ultrathin epitaxial graphite: Two-dimensional electron gas properties and a route toward graphene-based nanoelectronics. *Journal of Physical Chemistry A*, *B108*, 19912–19916. https://doi.org/10.1021/jp040650f

Beun, S., Glorieux, T., Devaux, J., Vreven, J., & Leloup, G. (2007). Characterization of nanofilled compared to universal and microfilled composite. *Dental Materials*, *1*(1), 51–59. https://doi.org/10.1016/j.dental.2005.12.003

Bharathiraja, B., Sudharsana, T., Jayamuthunagai, J., Praveenkumar, R., Chozhavendhan, S., & Iyyappan, J. (2018). Biogas production – A review on composition, fuel properties, feed stock and principles of anaerobic digestion. *Renewable and sustainable Energy Reviews*, *90*(April), 570–582. https://doi.org/10.1016/j.rser.2018.03.093

Bogue, R. (2011). Nanocomposites: A review of technology and applications. *Assembly Automation*, *31*(2), 106–112. https://doi.org/10.1108/01445151111117683

BORSA, C. E., JIAO, S., TODD, R. I., & BROOK, R. J. (1995). Processing and properties of Al2O3/SiC nanocomposites. *Journal of Microscopy*, *177*(3), 305–312. https://doi.org/10.1111/j.1365-2818.1995.tb03561.x

Brar, S., Verma, M., Tyagi, R., & Surampalli, R. (2010). Engineered nanoparticles in wastewater and wastewater sludge – Evidence and impacts. *Waste Management*, *30*(3), 504–520. https://doi.org/10.1016/j.wasman.2009.10.012

Chandki, R., Kala, M., Kumar, N. K., Brigit, B., Banthia, P., & Banthia, R. (2012). 'Nanodentistry: Exploring the beauty of miniature. *Journal of Clinical and Experimental Dental*, *4*(2), e119–24. https://doi.org/10.4317/jced.50720

Chen, M., Chen, H., C, R., Hsu, S., Sun, H., S, P., & Su, W. F. (2006). Low shrinkage light curable nanocomposite for dental restorative material. *dental Materials*, *22* (2), 138–145. https://doi.org/10.1016/j.dental.2005.02.012

Chen, Y., Liu, T., He, H., & Liang, H. (2018). Fe_3O_4/ZnMg(Al)O magnetic nanoparticles for efficient biodiesel production. *ApplOrganomet Chem*, *32*, 1–10. https://doi.org/10.1002/aoc.4330

Choa, Y. H., Yang, J. K., Kim, B., . H., Jeong, Y.-K., Lee, J.-S., Nakayama, T., Sekino, T., & Niihara, K. (2003). Preparation and characterization of metal: Ceramic nanoporous nanocomposite powders. *Journal of Magnetism and Magnetic Materials*, *266*(1–2), 12–19. https://doi.org/10.1016/S0304-8853(03)00450-5

Chung, D., D, L., & Mater, J. (2004). Electrical applications of carbon materials. *Journal of Materials Science*, *39* (8), 2645–2661. https://doi.org/10.1023/B:JMSC.0000021439.18202.ea

DeLuca, N., Elabd, W., & Y, A. (2006). Polymer electrolyte membranes for the direct methanol fuel cell: a review. *Journal Polymer Science Part B Polymer Physics*, *44*(16), 2201–2225. https://doi.org/10.1002/polb.20861

Din, S., Shah, H., M, A., & Sheikh, N. A. (2016). Effect of CVD-diamond on the tribological and mechanical performance of titanium alloy (Ti_6Al_4V). *Tribology in Industry*, *38*, 530–542. https://europub.co.uk/articles/-A-228385

European Commission. (2011). Commission recommendation of 18 October 2011 on the definition of nanomaterial (2011/696/EU). *Official Journal of the European Union*, *54*, 38–40. https://doi.org/10.3000/18770677.L_2011.275.eng

Fortin, D., & Vargas, N. A. (2000). The spectrum of composites: New techniques and materials. *Journal of the American Dental Association (1939)*, *131*(6), 26S–30S. https://doi.org/10.14219/jada.archive.2000.0399

Gangopadhyay, R., & Amitabha, D. (2000). Conducting polymer nanocomposites: A brief overview. *Chemistry of Materials*, *12*(7), 608–622. https://doi.org/10.1021/cm990537f

Giannelis, E. P. (1996). Polymer layered silicate nanocomposites. *Advanced Materials*, *8*(1), 29–35. https://doi.org/10.1002/adma.19960080104

Gleiter, H. (1992). Materials with ultrafine microstructures: Retrospectives and perspectives. *Nanostructured Materials*, *1*(1), 1–19. https://doi.org/10.1016/0965-9773(92)90045-Y

Guo, Z., Wei, S., Shedd, B., Scaffaro, R., Pereira, T., Hahn, H. T., & Mater, J. (2007). Particle surface engineering effect on the mechanical, optical and photoluminescent properties of ZnO/vinyl-ester resin nanocomposites. *Chemistry*, *17*, 806–813. https://doi.org/10.1039/b613286c

Hafeez, M. (2022). *Recent progress and overview of nanocomposites*. (Ed.), Nanocomposite Materials [Working Title]. IntechOpen. https://doi.org/10.5772/intechopen.102469

Harmsen, P. F. H., Hujigen, W., Bermudez, L., & Bakker, R. (2010). *Literature review of physical and chemical pretreatment processes for lignocellulosic biomass*. Wageningen UR Food and Biobased Research. https://edepot.wur.nl/150289

Hench, L., West, L., & J, K. (1990). The sol-gel process. *Chemical Review*, *90*(1), 33–72. https://doi.org/10.1021/cr00099a003

Iavicoli, I., Leso, V., Beezhold, D. H., & Shvedova, A. A. (2017). Nanotechnology in agriculture: Opportunities, toxicological implications, and occupational risks. *Toxicology and Applied Pharmacology*, *329*, 96–111. https://doi.org/10.1016/j.taap.2017.05.025

Kapoor, D., Vyas, R. B., Lad, C., Patel, M., & Lal, B. (2015). Role of nanocomposites in drug delivery – A review. *International Journal of Nanotechnology and Nanoscience*, *3*, 10–15. https://www.researchgate.net/publication/337193082_

Karthiga, D. G., Suruthi, P., Veerakumar, R., Vinoth, S., Subbaiya, R., & Chozhavendhan, S. (2019). A review on metallic gold and silver nanoparticles. *Research Journal of Pharmacy and Technology*, *12*(2), 935–943. https://doi.org/10.5958/0974-360X.2019.00158.6

Keng, P., Lee, S., S, L., Ha, S. T., & Ong, S.-T. (2014). Removal of hazardous heavy metals from aqueous environment by low-cost adsorption materials. *Environmental Chemistry Letters*, *12*(1), 15–25. https://doi.org/10.1007/s10311-013-0427-1

Kojima, Y., Usuki, A., Kawasumi, M., Okada, A., Fukushima, Y., Kurauchi, T., & Kamigaito, O. (1993). Mechanical properties of nylon-6-clay hybrid. *Journal of Materials Research*, *8*(5), 1185–1189. https://doi.org/10.1557/JMR.1993.1185

Koo, J. H. (2006). *Polymer Nanocomposites*. McGraw-Hill Professional Pub.

Kuila, B., Nandan, B., Böhme, M., Janke, A., & Stamm, M. (2009). Chemical communication. *Chemical Communications (Cambridge, England)*, (38), 5749–5751. https://doi.org/10.1039/b912513b

Kumar, A., Shalini Sharma, G., Sharma, G., Naushad, M., Kumar, A., Kalia, S., Guo, C., & Mola, G. T. (2017). Facile hetero-assembly of superparamagnetic Fe_3O_4/$BiVO_4$ stacked on biochar for solar photo-degradation of methyl paraben and pesticide removal from soil. *Journal of Photochemistry and Photobiology A: Chemistry*, *337*, 118–131. https://doi.org/10.1016/j.jphotochem.2017.01.010

Kundu, T. K., Mukherjee, M., Chakravorty, D., & KUNDU, T. K. (1998). Growth of nano-alpha-Fe2O3 in a titania matrix by the sol gel route. *Journal of materials Science*, *33*(7), 1759–1763. https://doi.org/10.1023/A:1004376515384

Lade, B. D., Gogle, D. P., & Nandeshwar, S. B. (2017). Nano bio pesticide to constraint plant destructive pests. *Journal of Nanomedicine Research*, *6*(3), 00158. https://doi.org/10.15406/jnmr.2017.06.00158

Li, C., Chen, G., Sun, J., Rao, J., Han, Z., Hu, Y., Xing, W., & Zhang, C. (2016). Doping effect of phosphate in Bi2WO6 and universal improved photocatalytic activity for removing various pollutants in water. *Applied Catalysis B: Environmental*, *188*, 39–47. https://doi.org/10.1016/j.apcatb.2016.01.054

Liu, T., Phang, X., I, Y., & Shen, L. (2004). Morphology and mechanical properties of multiwalled carbon nanotubes reinforced nylon-6 composites. *Macromolecules*, *37*(19), 7214–7222. https://doi.org/10.1021/ma049132t

Lohbauer, U., Frankenberger, R., Kramer, N., Petschelt, A., Biomed Mater, J., & Res Part, B. (2006). Strength and fatigue performance versus filler fraction of different types of direct dental restoratives: Appl biomater. *Journal of Biomedical*

Materials Research Part B, *76*(1), 114–120. https://doi.org/10.1002/jbm.b.30338

Lusic, H., & Grinstaff, M. W. (2013). X-ray-computed tomography contrast agents. *Chemical Reviews*, *113* (3), 1641–1666. https://doi.org/10.1021/cr200358s

Mahmood, T., Ullah, A., & Ali, R. (2022). *Improved nanocomposite materials and their applications*. Ed. Nanocomposite Materials [Working Title]. IntechOpen. https://doi.org/10.5772/intechopen.102538

Markets and Markets Research Private Ltd. (2019). Nanocomposites market. Report Code: CH 7226. https://www.marketsandmarkets.com/Market-Reports/nanocomposites-market-141476334.html

Mayworm, C., Camargo, D., J, S., Bastian, S., F, L., & Dent, J. (2008). Influence of artificial saliva on abrasive wear and microhardness of dental composites filled with nanoparticles. *Journal of dentistry*, *36*(9), 703–710. https://doi.org/10.1016/j.jdent.2008.05.001.

Menossi, M., Casalongué, C., & Alvarez, V. A. (2022). Bionanocomposites for modern agricultural applications. In *Handbook of consumer nanoproducts* (pp. 1201–1237). Springer Nature Singapore. https://doi.org/10.1007/978-981-15-6453-6_68-1

Min, K., & Yoo, Y. (2014). Recent progress in nano biocatalysis for enzyme immobilization and its application. *Biotechnology and Bioengineering*, *19*, 553–567. https://doi.org/10.1007/s12257-014-0173-7

Mittal, H., Kumar, V., Saruchi Ray, S. S., & Ray, S. S. (2016). Adsorption of methyl violet from aqueous solution using gum xanthan/Fe_3O_4 based nanocomposite hydrogel. *International Journal of Biological Macromolecules*, *89*, 1–11. https://doi.org/10.1016/j.ijbiomac.2016.04.050

Naushad, M., Ahamad, T., Sharma, G., Al-Muhtaseb, A. H., Albadarin, A. B., Alam, M. M., ALOthman, Z. A., Alshehri, S. M., & Ghfar, A. A. (2016). Synthesis and characterization of a new starch/SnO_2 nanocomposite for efficient adsorption of toxic Hg2+ metal ion. *Chemical Engineering Journal*, *300*, 306–316. https://doi.org/10.1016/j.cej.2016.04.084

Niemeyer, C. M., & Doz, P. (2001). Nanoparticles, proteins, and nucleic acids: Biotechnology meets materials science. *Angewandte Chemie International Edition*, *40*(22), 4128–4158. https://doi.org/10.1002/1521-3773(20011119)40:22<4128::AID-ANIE4128>3.0.CO;2-S

Ogawa, M., & Kuroda, K. (1997). Preparation of inorganic composites through intercalation of organoammoniumions into layered silicates. *Bulletin of the Chemical Society of Japan*, *70*(11), 2593–2618. https://doi.org/10.1246/bcsj.70.2593

Orive, G., Hernández, R. M., Gascón, A. R., & Pedraz, J. L. (2005). Micro and nano drug delivery systems in cancer therapy. *Cancer Therapy*, *3*, 131–138.

Ortengren, U., Wellendorf, H., Karlsson, S., Ruyter, I. E., & Oral Rehabil, J. (2001). Water sorption and solubility of dental composites and identification of monomers released in an aqueous environment. *Journal of Oral Rehabilitation*, *28*(12), 1106–1115. https://doi.org/10.1046/j.1365-2842.2001.00802.x

Oskam, G. (2006). Metal oxide nanoparticles: Synthesis, characterization and application. *Journal of Sol-Gel Science and Technology*, *37*(3), 161–164. https://doi.org/10.1007/s10971-005-6621-2

Ounaies, Z., Park, C., & Wise, K. E. (2003). Electrical properties of single wall carbon nanotube reinforced polyimide composites. *Composites Science and Technology*, *63*(11), 1637–1646. https://doi.org/10.1016/S0266-3538(03)00067-8

Palaniappan, S., Bharadwaj, D., Mattar, D., Peumans, M., Van Meerbeek, B., Lambrechts, P., & Mater, D. (2009). Three-year randomized clinical trial to evaluate the clinical performance and wear of a nanocomposite versus a hybrid composite. *Dental Materials : Official Publication of the Academy of Dental Materials*, *25* (11), 1302–1314. https://doi.org/10.1016/j.dental.2009.06.001

Peigney, A., Laurent, C. H., & Flahaut, E. (2006). Carbon nanotubes in novel ceramic matrix nanocomposites. *Ceramics International*, *26*(6), 677–683. https://doi.org/10.1016/S0272-8842(00)00004-3

Rajamehala, M., Su, R., & Gopalakrishnan, B. (2022). Green synthesis of titanium dioxide and its application on anti-fungal activity. *Research Journal of Pharmacy and Technology*, *15*, 695–700. https://doi.org/10.52711/0974-360X.2022.00115

Ramsurn, H., & Gupta, R. (2013). Nanotechnology in solar and biofuels. *ACS Sustainable Chemistry & Engineering*, *1*(7), 779–797. https://doi.org/10.1021/sc400046y

Ray, S. S., & Okamoto, M. (2003). Polymer/layered silicate nanocomposites: A review from preparation to processing. *Progress in Polymer Science*, *28*, 1539–1641. https://doi.org/10.1016/j.progpolymsci.2003.08.002

Riedel, R., Strecker, K., & Petzow, G. (1989). In situ polysilane-derived silicon-carbide particulates dispersed in silicon nitride composite. *Journal of the American Ceramic Society*, *72*(11), 2071–2077. https://doi.org/10.1111/j.1151-2916.1989.tb06033.x

Schadler, L. S. (2003). *Polymer-Based and polymer-filled nanocomposites*. Wiley Online Library.

Schmidt, D., Shah, D., & Giannelis, E. P. (2002). New advances in polymer/layered silicate nanocomposites. *Current Opinion in Solid State & Materials Science*, *6*(3), 205–212. https://doi.org/10.1016/S1359-0286(02)00049-9

Schulz, H., Schimmoeller, B., Pratsinis, S. E., Salz, U., & Bock, T. (2008). Radiopaque dental adhesives: Dispersion of flame-made Ta2O5/SiO2 nanoparticles in methacrylic matrices. *Journal of Dentistry*, *36*(8), 579–587. https://doi.org/10.1016/j.jdent.2008.04.010

Sen, S., Choudharya, R. N. P., & Pramanik, P. (2004). Synthesis and characterization of nanostructured ferroelectric compounds. *Materials Letters*, *58*(27–28), 3486–3490. https://doi.org/10.1016/j.matlet.2004.06.063

Shah, M., Sheikh, A., N, A., Najar, K. A., Ramasubramanian, K., Balaji, S., & Ramachandra Rao, M. S. (2016). Influence of boron doping on mechanical and tribological properties in multilayer CVD diamond coating system. *Bulletin of Materials Science*, *39*(7), 1753–1761. https://doi.org/10.1007/s12034-016-1311-y

Sharma, G., Thakur, B., Naushad, M., Al-Muhtaseb, A. H., Kumar, A., Sillanpaa, M., & Mola, G. T. (2017). Fabrication and characterization of sodium dodecyl sulphate@ironsilico phosphate nanocomposite: Ion exchange properties and selectivity for binary metal ions. *Materials Chemistry and Physics*, *193*, 129–139. https://doi.org/10.1016/j.matchemphys.2017.02.010

Smith, K., Evans, D. A., & El-Hiti, G. A. (2008). Role of modern chemistry in sustainable arable crop protection. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *363*(1491), 623–637. https://doi.org/10.1098/rstb.2007.2174

Stankovich, S., & Mater, J. (2006). Stable aqueous dispersions of graphitic nanoplatelets via the reduction of exfoliated graphite oxide in the presence of poly

(sodium 4-styrenesulfonate). *Chemistry*, *16*, 155–158. https://doi.org/10.1039/B512799H

Stearns, L. C., Zhao, J., & Martin, P. (1992). Harmer processing and microstructure development in Al_2O_3-SiC 'nanocomposites'. *Journal of European Ceramic Society*, *10*(3), 473–477. https://doi.org/10.1016/0955-2219(92)90022-6

Sternitzke, M. (1997). Review: Structural ceramic nanocomposites. *Journal of European Ceramic Society*, *17*(9), 1061–1082. https://doi.org/10.1016/S0955-2219(96)00222-1

Stoeva, S. I., Huo, F., Lee, J. S., & Mirkin, C. A. (2005). Three-layer composite magnetic nanoparticle probes for DNA. *Journal of the American Chemical Society*, *127*(44), 153623. https://doi.org/10.1021/ja055056d

Su, L., Shi, X., Guo, G., Zhao, A., & Zhao, Y. (2013). Stabilization of sewage sludge in the presence of nanoscale zero-valent iron (nZVI): Abatement of odor and improvement of biogas production. *Journal of Material Cycles and Waste Management*, *15*(4), 461–468. https://doi.org/10.1007/s10163-013-0150-9

Tanimoto, Y., Kitagawa, T., Aida, M., & Nishiyama, N. (2006). Experimental and computational approach for evaluating the mechanical characteristics of dental composite resins with various filler sizes. *ActaBiomater*, *2*(6), 633–639. https://doi.org/10.1016/j.actbio.2006.06.006

Thompson, C. M., Herring, H. M., & Gates, T. S. (2003). Preparation and characterization of metal oxide/polyimide nanocomposites. *Composites Science and Technology*, *63*(11), 1591–1598. https://doi.org/10.1016/S0266-3538(03)00062-9

Viart, N., Richard-Plouet, M., Muller, D., & Pourroy, G. (2003). Synthesis and characterization of Co/ZnO nanocomposites: Towards new perspectives offered by metal/piezoelectric composite materials. *Thin Solid Films*, *437*(1–2), 1–9. https://doi.org/10.1016/S0040-6090(02)00785-X

Vorotilov, K. A., Yanovskaya, M. I., Turevskaya, E. P., & Sigov, A. S. (1999). Sol-gel derived ferroelectric thin films: Avenues for control of microstructural and electric properties. *Journal of Sol-Gel Science and Technology*, *16*(2), 109–118. https://doi.org/10.1023/A:1008776120997

Wang, L., Chen, Q. -D., Cao, X. -W., Buividas, R., Wang, X., Juodkazis, S., & Sun, H. -B. (2017). Plasmonic nanoprinting: large-area nanoscale energy deposition for efficient surface texturing. *Light: Science & Applications*, *6*(12), e17112–e17112.

Wang, H., Covarrubias, J., Prock, H., Wu, X., Wang, D., & Bossmann, S. (2015). Acid-functionalized magnetic nanoparticle as heterogeneous catalysts for biodiesel synthesis. *The Journal of Physical Chemistry C*, *119*(46), 26020–26028. https://doi.org/10.1021/acs.jpcc.5b08743

Wang, T., Zhang, D., Dai, L., Chen, Y., Dai, X., Cecchini, M., Piazza, V., & Gemmi, M. (2016). Effects of metal nanoparticles on methane production from waste-activated sludge and microorganism community shift in anaerobic granular sludge. *Scientific Reports*, *6*(1), 1–10. https://doi.org/10.1038/s41598-016-0001-8

Wennersten, R., Fidler, J., & Spitsyna, A. (2008). Nanotechnology: A new technological revolution in the 21st century. In K. B. Misra. (Ed.), *Handbook of performability engineering* (pp. 943–952). Springer. https://doi.org/10.1007/978-1-84800-131–2_57

Wypych, F., Seefeld, N., & Denicolo, I. (1997). Preparation of nanocomposites based on the encapsulation of conducting polymers into 2H-MoS_2 and 1T-TiS_2. *Quimica Nova*, *20*(4), 356–360. https://www.semanticscholar.org/paper/Prepara%C3%A7%C3%A3o-de-nanocomp%C3%B3sitos-atrav%C3%A9s-do-de-em-e-Wypych-Seefeld/bf39a841e8f1ac591a40fa5703a0a14c5ab7f1c2

Xiao, B., Byrne, P. J., Wheatley, P. S., Wragg, D. S., Zhao, X., Fletcher, A. J., Thomas, K. M., Peters, L., Evans, J. S., Warren, J. E., Zhou, W., & Morris, R. E. (2009). Chemically blockable transformation and ultraselective low-pressure gas adsorption in a non-porous metal organic framework. *Nature Chemistry*, *1*(4), 289–294. https://doi.org/10.1038/nchem.254

Xia, Y., Zhang, F., Xie, H., & Gu, N. (2008). Nanoparticle-reinforced resin-based dental composites. *Journal of Dentistry*, *36*(6), 450–455. https://doi.org/10.1016/j.jdent.2008.03.001

Xiong, Y., Cui, X., Zhang, P., Wang, Y., Lou, Z., & Shan, W. (2017). Improving Re (VII) adsorption on diisobutylamine-functionalized graphene oxide. *ACS Sustainable Chemistry & Engineering*, *5*(1), 1010–1018.

Zhang, Y., Small, J., Amori, P., & M, E. (2005). Electric field modulation of galvanomagnetic properties of mesoscopic graphite. *Physical Review Letters*, *94*(17), 176803. https://doi.org/10.1103/PhysRevLett.94.176803

© 2022 The Author(s). This open access article is distributed under a Creative Commons Attribution (CC-BY) 4.0 license.

You are free to:
Share — copy and redistribute the material in any medium or format.
Adapt — remix, transform, and build upon the material for any purpose, even commercially.
The licensor cannot revoke these freedoms as long as you follow the license terms.

Under the following terms:
Attribution — You must give appropriate credit, provide a link to the license, and indicate if changes were made.
You may do so in any reasonable manner, but not in any way that suggests the licensor endorses you or your use.
No additional restrictions

You may not apply legal terms or technological measures that legally restrict others from doing anything the license permits.

Cogent Engineering **(ISSN: 2331-1916) is published by Cogent OA, part of Taylor & Francis Group.**

Publishing with Cogent OA ensures:

- Immediate, universal access to your article on publication
- High visibility and discoverability via the Cogent OA website as well as Taylor & Francis Online
- Download and citation statistics for your article
- Rapid online publication
- Input from, and dialog with, expert editors and editorial boards
- Retention of full copyright of your article
- Guaranteed legacy preservation of your article
- Discounts and waivers for authors in developing regions

Submit your manuscript to a Cogent OA journal at www.CogentOA.com