

Use of Nano composites in industries

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ABSTRACT

High performance materials called Nano composites have unique features. Engineering plastics and elastomers are where Nano composites are most in demand, with an anticipated 25% annual growth rate. Their potential is so great that they are useful in many applications, from packaging to biomedical ones. The many forms of matrix Nano composites are covered in this review, with an emphasis on the need for these materials, their methods of manufacturing, and some recent findings regarding their structure, characteristics, and possible uses. The necessity for such materials in the future as well as other intriguing applications are projected. Applications of nano composites offer new technical and commercial potential for numerous sectors of the aerospace, automotive, electronics, and biotechnology industries because to their environmental friendliness.

INTRODUCTION

When at least one of the phases of a composite exhibits dimensions in the nanometer range, the composite is said to be a nano composites[1,2]. Although the term "nanotechnology" is new, functioning objects and structures with dimensions of a nanometer already exist. Roman glassmakers were creating glasses with Nano scale metals in the fourth century. Nano composite materials have emerged as suitable replacements for the absurd limitations of micro composites. They have been shown to be 21st-century resources in terms of design rarity and property groups that are not present in typical composites [3-5]. They do, however, provide preparation difficulties related to the control of fundamental structure and stoichiometry in the nanocluster phase. High performance materials called nanocomposites exhibit unusual property arrangements[6-8]. Their potential is so obvious that they are useful in a variety of applications, from packaging to biomedical ones. This research highlights the necessity of these materials by presenting several matrix nanocomposites. Their techniques of processing, composition, characteristics, and possible applications are discussed[9,10]. Due to their small size, high surface area, and phase relationships at their interfaces, nanocomposites imply unique features. They stand out for their potential to create high value added materials such as catalysts, biomaterials, and pharmaceuticals that work well. When the particle size falls below a specific threshold, referred to as "the critical size," it has been claimed that changes in particle attributes can be seen[11,12]. Interactions at phase interfaces typically improve when diameters approach the nanometer range. Additionally, the discovery of carbon nanotubes and their subsequent application to create composites that displayed some of the special mechanical, thermal, and electrical properties connected to carbon nanotubes provided a fresh and exciting dimension to this field. In addition to being ecologically beneficial, nanocomposites currently present new technological and commercial potential for all sectors of industry[13-15].

LITERATURE REVIEW AND HISTORY

Projections of nano-composites

Nanocomposites offer an exceptionally extensive range of prospective applications from electronics, optical communications and biological systems to new materials. Many possible applications have been explored and many devices and systems have been considered. More potential applications and new devices are being proposed. It is evidently impossible to recapitulate all the devices and applications that have been studied. It is interesting to note that the applications of nanocomposites in diverse fields have clearly different demands, and thus face different challenges, which require several strategies[16-18]. The reinforcements offer connecting parts and reflect the crack, preventing it from widening further. The volume increase caused by the stress field of a spreading fracture causes a phase transition in the integrated phase, which aids in the toughening and strengthening processes. Thanks to Niihara's ground-breaking

work, the potential of ceramic matrix nanocomposites, particularly the Al₂O₃/SiC system, was made clear. The crack-bridging function of the nanosized reinforcement served as the foundation for the toughening mechanism. High strength nanofibres have been combined with ceramic matrices to create advanced nanocomposites, which have higher toughness and better failure properties than ceramic materials[19, 20]. Projects involving space missions use extremely light spacecraft. Gyroscopes, gears, solar arrays, antennae, motors, sunshades, rovers, radars, solar concentrators, and reflector arrays are a few examples of the mobile mechanical components that make up these spacecraft components. These components will need to be produced from adaptable, flexible materials that can be folded or packaged in small quantities. This is essential because a big ultra-lightweight operational structure made of ultra-lightweight components will be mechanically deployed. All of the aforementioned qualities must be present in a single piece of material. Similar to this, to enhance ballistic performance, rocket propellants are made from a polymer-Al/Al₂O₃ nanocomposite[21–23].

Nanocomposites Handling

Al₂O₃, SiC, and SiN are examples of matrix materials used in ceramic metallic nanocomposites, whereas Al, Mg, Pb, Sn, W, and Fe are the most common metals used in metal matrix nanocomposites. Polymer matrix nanocomposites use a wide variety of polymers, such as vinyl polymers, condensation polymers, polyolefins, and specialty polymers. Crystalline reinforcements, such as clays, silica, TiO₂, and other metal oxides, as well as synthetic and natural metal powders, have all been employed. In a similar vein, chemical/vapour deposition techniques are mostly used to create carbon nanotubes. Utilizing surfactants, oxidation, or chemical functionalization of carbon nanotubes. Some of the methods used are surfaces. In the case of carbon nanotube-reinforced polymer composites, physical mixing and in situ polymerization are utilized to improve dispersion, whereas alignment of carbon nanotubes could be accomplished by methods such ex-situ techniques[24,25].

Nanocomposites's Properties and Structure

Nanoscale reinforcement components in the form of particles, fibers, nanotubes, and other structures make up the structure of nanocomposites. Atomic force microscopy (AFM), scanning tunneling microscopy (STM), Fourier transformed infrared spectroscopy (FTIR), X-ray photoelectron spectroscopy (XPS), nuclear magnetic resonance (NMR), differential scanning calorimetry (DSC), scanning and transmission electron microscopy (SEM/TEM), etc. have all been used to characterize the nanocomposites. Nanostructures and crystallite structures in various nanocomposites have recently been quantitatively characterized using simultaneous small angle X ray scattering (SAXS) and X ray diffractometry (XRD) studies[26–28]. In a nutshell, single-walled carbon nanotubes have a density that is less than one-sixth that of steel, whereas multi-walled carbon nanotubes have a density that is half that of aluminum.

Young's modulus values are comparable to those of diamond, while tensile strengths of single- and multi-walled carbon nanotubes are reported to be significantly higher than those of high strength steel. They have incredible robustness, which sets them apart from the plastic deformation of metals and the brittle fracture of carbon fibers. They can withstand bending to very large angles and restraughtening without suffering any harm. Similar to this, theoretical thermal and electrical conductivities have virtually minimal thermal expansion coefficients and are comparable to those of diamond. In contrast to the lower values observed for metal wires in microchips, they also display high parallel and perpendicular magnetic susceptibilities[29–30] and great thermal stability in both air and vacuum.

Ceramic Nanocomposites in a Matrix (CMNC)

The conventional powder method, the polymer precursor route, spray pyrolysis, vapour techniques, and chemical methods, such as the sol-gel process, colloidal and precipitation procedures, and template synthesis, are the most widely used methodology for the creation of CMNC. Ceramics are frequently fragile and prone to fracture as a result of crack growth. By adding a ductile metal phase or another ceramic to the matrix, ceramics can be made appropriate for engineering purposes. Because of the interaction between the various phases, the matrix, and the reinforcements at the phase boundaries, mechanical properties including hardness and fracture toughness are improved[31,32].

Nanocomposite systems with ceramic matrix-discontinuous reinforcement

When compared to its micro counterpart, the nanocomposite's strength has significantly improved. Due to the increased interfacial interaction between the particles in nanocomposites, the fracture strength is substantially higher. Furthermore, compared to the intergranular fracture seen in monolithic materials, Al₂O₃-5 to 15% SiC systems showed superficial grooves of plastic deformation. Additionally, Si₃N₄ fails at 0.3% strain after 0.4 hours at 1673 K and 200

MPa of tension, but the Si₃N₄/10% SiC nanocomposite did not fail until 1,000 hours at 1.5% strain. In terms of morphological analyses, Al₂O₃ and Fe₂O₃ ceramic matrix nanocomposites with a good distribution of Co and Ni nanoparticles have microstructures that are worth mentioning[33,34]. Both bending strength and fracture toughness increase with increasing volume of carbon nanotubes when the volume concentration of carbon nanotubes is smaller than 5% vol. However, these two qualities decline with loadings greater than 5%. When compared to monolithic SiO₂, the increase in strength and fracture toughness at 5 vol.% is up to 65 and 100%, respectively. According to the hypothesis of short fiber-reinforced composites, this improvement in mechanical qualities is the result of carbon nanotubes' superior mechanical capabilities and high aspect ratio. [35-37] Due to the carbon nanotubes' restriction, bending strength at high loading decreases. they express a higher chance of agglomeration during densification. Further, the The matrix's pull-out of carbon nanotubes increases with carbon nanotube addition. when stress is transferred. peculiar actions such enhanced contact-damage resistance have also been documented in without a corresponding increase in toughness. Nanotube/Al₂O₃ composites. These systems' microhardness rises as the The amount of carbon nanotubes is raised by up to 4%. Grain is probably to blame for this. effects of size and the carbon nanotubes' role in reinforcing. just like the carbon nanotube Wear losses also significantly increased when content climbed above 10 wt. (%)[38-40] SiC/carbon nanotube preparation demonstrated a 10% improvement in the strength and when compared to monolithic ceramics, fracture toughness These outcomes were attributed to fracture deflection and nanotube/matrix debonding. So as a result, There have been numerous attempts to enhance mechanical properties using the carbon nanotubes being incorporated into ceramic matrices. Nevertheless, the discovered The projected level of improvement was not reached. Carbon nanotubes with a single wall used in the spark-plasma sintering process for ceramic composite reinforcing compared to pure alumina, produced a 194% increase in fracture toughness. An rise of 24% In nanograined Al₂O₃ composite, an increase was seen in fracture toughness across the matrix. having a multi-walled carbon nanotube content of 10%, which was attributed to the Carbon nanotubes are oxidized before being dispersed. In this instance, the content was manufactured under three different conditions, including mixing, hot pressing (1573 K), and sintered to nearly Density in theory[41-43].

Nanocomposites with Metal Matrix (MMNC)

Major breakthroughs have accompanied the discovery of novel alloys. The discovery that intimately combining copper and tin produced a metal that was significantly stronger than copper led to the invention of bronze. The majority of metal-metal nanocomposites based on nanocrystals show a remarkable resistance to grain development, regardless of the synthesis process. In addition to the microstructural and compositional characteristics, porosity, impurities, grain size distribution, texture, and microstrain resulting from the processing of nanocrystalline materials are also related to thermal stability and the mechanisms involved in nanocrystalline materials. Two different metal nano composites can be simply mixed together to produce new qualities. Numerous studies have been conducted on nanocomposite systems like carbon nanotubes. The quantity of publications on the topic has consistently increased, occasionally even including evaluations. Reviews on PMNC cover processing issues, such as those involving layered silicates, conducting and biodegradable polymer-based systems, fiber reinforced, and structure, morphology, and property aspects, as well as applications and perspectives, such as important opportunities and difficulties in the creation of structural and functional fiber nanocomposites[44-46]. Spray pyrolysis, liquid metal infiltration, rapid solidification, vapor techniques, electrodeposition, and chemical procedures, including colloidal and sol-gel processes, are the methods utilized to process metal matrix nanocomposites. The fabrication of Fe-based nanocomposites involves solidification methods. The phrase "devitrified nanocomposite steel" is stressed by Branagan. The high nucleation frequency inside the constrained window for grain development prior to impingement was thought to be responsible for the production of nanophases. The wettability between the matrix and the particles was made better by the use of ultrasound[47-48].

METHODS

Discontinuous reinforcing systems for metal

A nice illustration of how unusual features may come from metal nanocomposites is the -Fe/Fe₂₃C₆/Fe₃B system. These two varieties of the Branagan and Tang alloy were found to have Vickers hardness values of 10.3 and 11 GPa in their as-solidified states. With increasing heat treatment temperature, the ribbon variety's hardness increased; it peaked at 16.2 GPa at 973 K and then decreased to 10.5 GPa at 1123 K. This is comparable to the ingot type's declining trend (8 and 6.6 GPa at 873 and 973 K respectively). The benefits of metal nanocomposites over their micro counterparts are likewise demonstrated by the Al/SiC system. The maximum value of 2.6 GPa for the sample with 10 vol% SiC represents a linear rise in hardness with increasing volume fraction of the harder phase (SiC). Young's and

shear modulus values considerably rise as SiC content rises, indicating the creation of a nanocomposite material with brittle SiC contained in a ductile Al matrix. The Young's modulus and hardness of Al/SiC nanocomposite are noticeably higher than those of its micro counterpart. For instance, the nanocomposite exhibits increases in hardness of 12.6% and Young's modulus of 105.1%. Al/Pb nanocomposites also have better frictional characteristics [49–51].

Composites made of metal and carbon nanotubes

As compared to the value of 3.4 cm for the Al matrix, the electrical characteristics of an Al/carbon nanotube system increased from 4.9 to 6.6 cm at ambient temperature for 1 and 4 wt. (%) carbon nanotubes but decreased to 5.5 cm for 10 wt. (%) carbon nanotubes. At lower temperatures, all composites' resistivities fell linearly, just like with metals, with a sharp decline of roughly 90%. Contrarily, compression testing of these Al-carbon nanotube composites revealed identical stress-strain curves, with the exception of significant elastic strain, for both the composite without the precursor and pure Al, while those containing the precursor, despite having a similar shape, showed higher compression stresses. Proof stress increased seven times at a larger multiwall carbon nanotube loading (1.6 vol.%) compared to a less noticeable increase in polymer-carbon nanotube composites. The containment of the Al matrix by the multi-walled carbon nanotubes on the nanoscale has been suggested as the cause of the improved mechanical properties [52–55].

Strengthening Mechanisms in Metal Matrix Composites

The thermal mismatch causes dislocations to occur at the reinforcement/matrix interface during cooling. The matrix is indirectly strengthened as a result of the thermally induced dislocation punching. The thermally-induced dislocations in age-hardenable matrix materials act as heterogeneous nucleation sites for precipitate production during the aging treatment[56,57].

Nanocomposites with a polymer matrix and discontinuous reinforcement that are not layered According to their dimensions

The reinforcing elements used to create polymer nanocomposites can be divided into different groups. Spherical silica, metal atoms, and semiconductor nanoclusters are a few examples. Nanotubes, also known as whiskers, are the second type of reinforcement. They have two dimensions on the nanometer scale and one bigger, providing an extended structure. This second group can comprise cellulose whiskers and carbon nanotubes, which have both been extensively explored as reinforcing nanofillers[58-60]. The single dimension in the nanometer range that distinguishes the third form of reinforcement is that dimension. The filler in this group consists of sheets that range in thickness from a few nanometers to several hundred to thousands of nanometers. The term "polymer-layered nanocomposites" refers to this family. Numerous man-made and organic crystalline hosts that can intercalate a polymer under particular circumstances have been described. Graphite, metal chalcogenides, clays, layered silicate, and layered double hydroxides are a few examples. Due to the accessibility of clay starting materials and their superior intercalation chemistry, clay-based nanocomposites have often been investigated[61–63].

RESULT

Stacked reinforcements in polymer nanocomposites

The subject of polymer layered silicate nanocomposites has attracted significant attention despite the fact that the chemistry of polymers towards layered silicates has long been known. First, the Nylon-6 (N6)/montmorillonite nanocomposites results, which demonstrated that variations in thermal and mechanical properties were significantly influenced by the concentration of layered silicate. Second, Vaia et al. found that polymers and layered silicates can be melted together without the need of organic solvents. The mechanical characteristics of a Nylon-6 matrix have been noticeably improved by the addition of montmorillonite. When the nanocomposite was created, the Young's modulus (or tensile modulus), for instance, of pure Nylon-6 (1.11 GPa), was significantly increased. The Nylon-6/MMT gave a value of 2.25 GPa, which is an increase of 102.7%, and had a filler content of 4.1 wt. (%). Additionally, with relation to Nylon-6 nanocomposites, hydrogen bond production results in a powerful interaction between the matrix and silicate layers. Maleic anhydride modified by propylene (PP-MA)/LS nanocomposites can also enable this behavior[64–66]. The tension at break increased dramatically in exfoliated Nylon-6 and intercalated PMMA nanocomposites. This might be a result of the silicate layers' polar (PMMA) and ionic (Nylon-6 grafted onto the layers) interactions with the matrix. In nanocomposites made of nylon-6, this rise is greater. The lack of interfacial adhesion between non-polar PP and polar-layered silicates can be used to explain why propylene-based nanocomposites only showed a modest increase in tensile stress. However, it has been demonstrated that adding polypropylene that has been treated with maleic anhydride

to the polypropylene matrix is beneficial in intercalating the PP chains and maintaining the final stress at a desirable level. Weak interactions at the polystyrene-clay contact are said to be responsible for this discovery. It is crucial to remember that in earlier compositions when polar contacts had occurred, it was shown that the filler matrix interface was strengthening. The elongation at break is often decreased when LS are disseminated in thermoplastics such as PMMA, PS, or PP [67-70]. From 150% in a pure PP matrix to 105% for a 6.9 wt. (%) non-intercalated clay microcomposite, elongation is stated to have decreased. However, a nanocomposite with 5 weight percent silicate layers showed a more pronounced reduction of 7.5%. Contrarily, elastomeric epoxy or polyol polyurethane matrices did not experience this decrease in ultimate elongation. In these situations, the nanoclay is introduced into cross-linked matrices, which increases the elongation at break. While the conventional composite's elongation at break appears to have decreased, the intercalated nanocomposite has shown a little improvement in this property[71-73]. Finally, the elongation at break is significantly increased in exfoliated nanocomposites. This is most likely caused by the galleries' plasticizing effects, their role in the development of dangling chains, and conformational effects at the clay-matrix interface. Elastomeric nanocomposites are good prospects for the development of a new family of high performance materials due to their enhanced stiffness (Young's modulus), toughness (stress at break), and elasticity (strain at break). Another material made of a polymer matrix that exhibits increased stress and elongation at break is polyimide. These qualities, for instance, rise with filler loading of at least 5 wt (%) when filled with montmorillonite exchanged with hexadecylammonium. Due to the production of non-exfoliated aggregates that make these composites more brittle, both characteristics decline towards values lower than those described for the filler-free matrix with greater filler contents[74,75]. Nylon-6 protonated aminododecanoic acid has also been extensively researched as a nanocomposite system for its impact resistance capabilities. When 4.7 wt (%) of nanoclay was added to the nanocomposite created by in situ intercalative polymerization, its Izod impact strength decreased from 20.6 to 18.1 J/m in comparison to the pure matrix. Charpy impact testing for the 4.7 wt (%) nanocomposite revealed a similar decrease from 6.21 kJ/m² to 6.06 kJ/m². This material has replaced glass fiber-reinforced nylon or polypropylene in the manufacture of timing belt covers for automobile engines due to its excellent impact resistance, high Young's modulus, good flexural modulus, and significant improvement in the heat distortion temperature, which increased from 338 K for pure Nylon-6 to more than 423 K for the nanocomposite.

DISCUSSION

The discussion presented in the given result highlights the significant attention that polymer-layered silicate nanocomposites have garnered in recent years. The addition of layered silicates to polymer matrices has been shown to improve their thermal and mechanical properties. The study particularly focuses on the impact of stacked reinforcements in these nanocomposites.

The results demonstrate that the addition of montmorillonite to Nylon-6 significantly improves the Young's modulus of the resulting nanocomposite. The increase in the tensile modulus is attributed to the strong interaction between the matrix and silicate layers resulting from hydrogen bond production. The study also shows that the polar and ionic interactions between the matrix and silicate layers result in a dramatic increase in the tension at break in exfoliated Nylon-6 and intercalated PMMA nanocomposites.

The discussion further points out that the lack of interfacial adhesion between non-polar PP and polar-layered silicates results in a modest increase in tensile stress in propylene-based nanocomposites. However, adding maleic anhydride-treated polypropylene to the matrix results in intercalating the PP chains, which maintains the final stress at a desirable level.

The study also reveals that while the elongation at break in LS-disseminated thermoplastics such as PMMA, PS, or PP decreases, it increases in elastomeric epoxy or polyol polyurethane matrices. The increase in elongation at break in exfoliated nanocomposites is attributed to the galleries' plasticizing effects and their role in the development of dangling chains and conformational effects at the clay-matrix interface.

CONCLUSION

Innovative materials must have distinct characteristics and improved performance. Nanocomposites are thus the right kind of materials to address the growing demands brought on by technological and scientific advancements. The difficulties in processing different kinds of nanocomposites present chances for researchers to solve issues with nanosize materials. They offer superior performance compared to comparable materials, making them suitable for overcoming the limitations of many currently used materials and systems. These materials have a wide range of possible uses in the field of engineering. These materials have a predicted demand in a number of industries because to

their superior mechanical, gas barrier, and flame-related qualities. As a result, all varieties of nanocomposites present opportunities and benefits, generating interest in these novel materials on a global scale.

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