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# A REVIEW ON THERMAL AND MECHANICAL PROPERTIES OF NANO COMPOSITES MATERIALS

**SK. IRFAN**, UG Student, Dept of Mechanical Engineering, NRI Institute of Technology Vijayawada, AP, INDIA-521212
**Dr. P. SIVA NAGASREE**, Associate Professor, Dept of Mechanical Engineering, NRI Institute of Technology, Vijayawada, AP, INDIA- 521212.
**K. SIVAMANI TEJA,** UG Student, Dept of Mechanical Engineering, NRI Institute of Technology Vijayawada, AP, INDIA-521212
**M.SUBHASH**, UG Student, Dept of Mechanical Engineering, NRI Institute of Technology Vijayawada, AP, INDIA-521212

## ABSTRACT
During the last two decades, the field of nanocomposite materials has attracted the attention of engineers and industries. Most of the industries are using nanocomposites to improve the properties of materials. A nanocomposite is a composite material, in which one of the components has at least one dimension that is nanoscopic in size that is around 10-9 m. Nanocomposite material is constituted by a matrix and a reinforcement consisting of nanoparticles. In the nanocomposite, the nanoparticles are added to the composite to improve the properties and characteristics of the material. This paper begins by introducing the concept of Nanocomposites and the types of Nanocomposites. In this paper, different types of nanocomposite materials and the improvement of properties are studied.

**keywords**:
Nanocomposite, Properties, Reinforcement, Matrix.

## I. Introduction
The word nanocomposite was first introduced by Blumstein in 1961.The primitive nanocomposite was investigated in an attempt to improve the thermal stability of nano silicate reinforced polymethyl methacrylate (PMMA) in 1965. Nanocomposites share similar terminologies as conventional composites in terms of their constituents except for the reinforcement size that is typically in the range of hundreds of nano meters. The reduction from micro-range to nano-range of fillers provides remarkable reinforcements in nanocomposites while requiring much lower content of fillers than the composites with conventional sizes (hereafter, call composites or conventional composites for short), hence leading to inconsiderable increases in weight

One of the desirable end-goals of materials science research is the development of multi-functional materials. These materials are defined as compositions that bring more than one property enhancement to a particular application, thus allowing the material to replace more than one other material in an engineered object, or to replace entire classes of materials which alone, are only capable of addressing one end-use need. The properties of the nanocomposite materials depend not only on the properties of their individual parents but also on their morphology and interfacial characteristics. Fabrication process and controlling the nano particles dispersion the mechanical properties like strength, flexural strength, toughness and hardness, stiffness, elongation and thermal stability, adhesion resistance can be improved.

The nanocomposite material is a product having nano-particles dispersed in a matrix. There are very small amounts of these nano-particles are added to the composites, and could result in significant loss in weight (as compared with the ancestral material to be replaced) and with great enhancement in the properties and making the composite usable for versatile applications as compare to micro scale particles where loading is much higher to achieve the similar performance. The correct selection of the particle is essential to ensure the improvement in the desired properties, undesired nano- particles may lead to different properties. Besides increasing general properties like mechanical properties, electrical properties, optical properties, these materials can be effectively used to protect the environment

### 1.1 NANOCOMPOSITES CLASSIFICATION

Nanocomposite materials can be divided into three groups, similar to micro composites, based on their matrix divided into 3 types

- Metal, Polymer and Ceramic Matrix Nanocomposites (MMNC, PMNC and CMNC): Metal Matrix Nanocomposites (MMNC): Metal matrix composites (MMCs), like other composites, are made up of at least two physically and chemically different phases that are dispersed in such a way that they provide properties that neither of the separate phases can provide. These nano composite MMNC are made up of a ductile alloy or metal matrix with nanosized reinforcing material. These materials have ceramic and metal properties, such as toughness and ductility, as well as high modulus and strength. As a result, these nanocomposites are highly suited for the creation of materials with high service temperatures and shear/compression strengths. They offer significant potential for usage in a multitude of disciplines, including the automotive and aerospace industries, as well as structural material manufacture
- Polymer Matrix Nanocomposites (PMNC): The most common type of nanocomposite is PMNC, which consist of isolated nano scale particles evenly distributed in a polymer in an ideal situation. The polymer matrix is used to disperse agglomerated nanoparticles in reality. Functional nanocomposites with better physical properties open up new possibilities in micro-optics, electronics, energy conversion, and storage.
- Ceramic Matrix Nanocomposites (CMNC): Ceramic matrix nanocomposites (CMNC), particularly the aluminium oxide (Al2O3)/silicon carbide (SiC) system, have a lot of potential. All the investigation has proven that the addition of low volume fraction (˷10%) of SiC with a specific size for Al2O3 matrix gives good improvement in the properties of matrix. The crack-bridging role of nanosized reinforcements has been used in certain research to explain this toughening mechanism. As a result of incorporating high-strength nanofibers into ceramic matrices, innovative nanocomposites with superior failure and high toughness characteristics have been developed in comparison to rapid failures of ceramic materials.

### 1.2 APPLICATIONS OF NANOCOMPOSITES

The nanocomposite applications introduces you to many of the uses being explored, including:

- Producing batteries with greater power output
- Speeding up the healing process for broken bones.
- Producing structural components with a high strength-to-weight ratio.
- Using graphene to make composites with even higher strength-to-weight ratios.
- Making lightweight sensors with nanocomposites.
- Using nanocomposites to make flexible batteries.
- Making tumors easier to see and remove.

## II. Literature

In this paper we consider and studied following journal publications as follows:
Francisco Sebastian Navarro Oliva et al.,[1] They proposed the case of PVDF-$Fe_3O_4$ nano-composites. In this study they investigate the impact of NP size on PVDF - $Fe_3O_4$ nanocomposite films, focusing on morphology, mechanical properties, and physical properties. Results show that nanoparticle size enhances mechanical properties but inhibits β-polymorph crystallization. This study examines the

morphology of electro spun fibers of PVDF, PVDF- $Fe_3O_4$, and PVDF- $Fe_3O_4$ (7 nm) using XRD patterns.

M.A. Morsi et al.,[2] They proposed the CMC/PAM blend was used to fabricate nanocomposite samples reinforced with cubic lithium titanate nanoparticles. The nanocomposite's structural, optical, thermal, mechanical, and dielectric properties were investigated. $Li_4Ti_5O_{12}$ NPs improved thermal stability, mechanical properties, and dielectric parameters, making them attractive biodegradable polymer nano-dielectrics.

L. Tharanikumar et al.,[3] In this study they examines microstructural and mechanical properties of nano $Si_3N_4$-BN hardened AleZneMg alloy hybrid nanocomposites synthesized using vacuum-assisted stir casting. Microstructure evaluation shows uniform nano reinforcing particles, with crystalline size of 44.9 nm. The composites increase tensile and compressive strength, with Al2Cu acting as corrosion-resistant. The results showed uniform reinforcement distribution, increased hardness to 70.27%, and increased ultimate strength. The homogeneous distribution of $Si_3N_4$ and BN led to high dislocation density and compressive strength.

Md. Alamgir1 et al.,[4] In this study the Polymer matrix nanocomposites have gained attention for their lightweight, stiffness, and strength properties. However, limited research has focused on biomedical applications. Phenolic nanocomposites reinforced with nano clay and $TiO_2$ were synthesized using twin-screw extruder machines. XRD results showed crystalline substances, while FTIR analysis showed nano clay mixed properly. Nano clay improves mechanical strength, while $TiO_2$ affects properties.

Md Golam Rasul et al.,[5] In this study the PE-boron nitride nanocomposites improve electrical insulation and thermal management by increasing tensile, flexural, and storage modulus. The nanocomposites offer enhanced mechanical and thermal properties, making them ideal for insulation materials and electronic device thermal interface layers. Results showed significant improvements in TMOE, FMOE, and tensile strength, with minimal thermal stability and significant reductions in CTE.

Adnan Khan et al.,[6] In this study they study developed and characterized Al-SiC-$ZrO_2$ nanocomposites, reinforced with SiC and $ZrO_2$ nanoparticles. Microstructural analysis revealed uniform reinforcement distribution, and mechanical properties increased with $ZrO_2$ concentration. These composites exhibit superior hardness, yield strength, and compressive strength, making them attractive for industrial applications.

Yanga et al.,[7] In this study 3D copper nanowires-thermally annealed graphene aerogel framework prepared through freeze-drying, thermal annealing, and epoxy resin fabrication. CuNWs-TAGA/epoxy nanocomposites exhibit high thermal conductivity, EMI SE, electrical conductivity, and elasticity modulus. CuNWs-TAGA/epoxy nanocomposites with good crystallinity, diameter, and length are prepared, achieving a maximum $\lambda$ value of 0.51 W/mK and excellent conductive network structures.

Jammula Koteswararao et al.,[8] In this study the Cadmium Sulfide nanoparticles were synthesized using hydrothermal methods and dispersed in PVA matrix. PVA/CdS nanocomposite films were analyzed for mechanical and structural properties. FTIR, XRD, SEM, and DSC showed varying degrees of agglomerated CdS nanoparticles. Increased CdS content improved mechanical properties. The addition of CdS in PVA hosts significantly impacts the properties of the nanocomposite.

Kusmono et al.,[9] In this study Chitosan-based nanocomposites films with clay loadings and glycerol added were investigated for thermal, mechanical, water absorption, and antimicrobial properties. XRD results showed intercalated structures, enhanced thermal stability, and improved tensile strength and modulus. Chitosan-based nanocomposites were produced using solution casting, with clay and glycerol added for strength, stiffness, and thermal stability. Clay increased strength, glycerol decreased stiffness, and improved intercalation.

Mingrui Liua et al.,[10] In this study a magnetic field alignment technique improves tensile strength and thermal conductivity of SWNTs/epoxy composites, enhancing tensile strength and thermal

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conductivity in research and industrial applications. The study demonstrates $Fe_2O_3$ nanoparticles can enhance alignment, mechanical properties, and thermal conductivity of polymer composites by attaching them to SWNTs using NaDDBS in a water solution.

A. Devaraju et al.,[11] In this the study they examines tensile, impact, and flexural properties of palm fiber composites with and without ZnO NP nano-particles. Results show NaOH treatment enhances mechanical properties at lower cost. Polymer composite material with NaOH treated palm fibers and epoxy resin added to 0.1 wt% ZnO NP increases tensile strength and impact energy, making it a promising green, low-cost, and environmentally friendly substitute for wood in indoor and automotive applications.

A. Wagiha et al.,[12] In this study Hybrid Cu-$Al_2O_3$ nanocomposites with GNPs coated Ag exhibit improved mechanical, electrical, and thermal properties, with compressive strength and hardness significantly improved. Thermal expansion and electrical conductivity are reduced, with 1.2% GNPs content reducing thermal conductivity.

Lubna Ahmed et al.,[13] This paper introduces the use of fire retardant nanofillers for enhanced flame retardancy and mechanical properties. It investigates the thermal degradation mechanism of neat polystyrene, PS-silica, and PS-montmorillonite nanocomposites. Results show improvement in thermal stability, char yield, and agglomeration, with nano silica and nano clays significantly improving thermal stability and mechanical properties.

Alireza Ashori et al.,[14] This study shows improved mechanical and thermo-mechanical properties of short carbon fiber/polypropylene composites by coating them with exfoliated graphene nanoplatelets. The composites showed increased tensile strength, modulus, and impact strength, while also improving storage modulus and damping capacity.

Mohamed H et al.,[15] In this study the Thermoset polymers are used in engineering components, adhesives, and fiber-reinforced composites due to their mechanical properties. However, they are brittle and vulnerable to cracking. Nano-cellulose, produced via electrospinning, improves fracture toughness in epoxy matrix by increasing flexural strength and modulus. The nanocomposites showed efficient stress transfer, increased critical stress intensity factor, and rougher fracture surfaces.

Sung-Chiun Shiu et al.,[16] This study investigates the thermal and mechanical properties of graphene/epoxy nanocomposites using molecular dynamics simulation. It combines three formats of graphene: graphene flakes, intercalated graphene, and intercalated graphene oxide. Results show intercalated graphene nanocomposites have higher Young's modulus, glass transition temperature, and thermal expansion coefficient were increased.

Marcos N et al.,[17] This study investigates the thermal and mechanical behaviors of photocurable epoxy acrylate resin nanocomposites with MWCNTs. Results show increased stiffness, hardness, glass transition temperature, and elastic modulus, with a fair agreement between nanoindentation and microhardness measurements. This work shows that nanocomposites with MWCNT improve their nanomechanical properties, with the highest reinforcement ratio observed in 0.75% cured for 12 hours.

Hongwei He et al.,[18] In this Study they evaluates nano-$CaCO_3$ particles' impact on epoxy resin cast properties using TGA and mechanical tests, revealing improved thermal stability and strength. The nano- $CaCO_3$ particles' impact on epoxy resin cast and composites, showing good dispersion and enhanced thermal stability and mechanical properties.

Pin-Ning Wang et al.,[19] In this study the Graphene nanoplatelets and carbon nanotubes enhance mechanical properties of epoxy composite and epoxy/carbon fiber composite laminates by enhancing ultimate tensile strength and flexure properties, resulting in significant improvements. Experimental results show optimal mechanical properties of CNTs/GNPs/epoxy nanocomposites and CNTs/GNPs/epoxy/carbon fiber composite laminates with reinforcement, improved tensile strength, flexure, and interlaminar shear strength.

I. M. Inuwa et al.,[20] In this study they investigates the impact of graphene nanoplatelets (GNP) and multiwall carbon nanotube (MWCNT) hybrid nanofillers on the mechanical and thermal properties of reinforced polyethylene terephthalate (PET). The nanocomposites were blended using a twin screw extruder and injection molding, and their morphology, mechanical, and thermal properties were characterized. The hybrid nanocomposites showed significantly improved mechanical properties and thermal stability compared to single filer nanocomposites.

Abdulrahman Khamaj et al.,[21] In this study they studied the composite improves mechanical and thermal properties, with improved hardness, thermal conductivity, and CTE. The effect of GNPs content on structural, mechanical, and thermal properties, and investigated the effect of sintering temperature. The nanocomposites are highly promising for heat sink applications due to their lightweight, high thermal conductivity, hardness, and low coefficient of thermal expansions.

Natrayan Lakshmaiya et al.,[22] This research explores the impact of oil palm shell (OPS) filler materials on interlaminar shear and dynamic properties of flax fiber-reinforced hybrid composites under cryogenic conditions. Results show OPS nanoparticles can be used as natural fillers, and a 4% OPS nanofiller improves storage and loss modulus.

Yiyi Zhang et al.,[23] In this study the cellulose insulation paper in oil-immersed transformers faces thermal ageing due to poor thermal conductivity and stability. Nano-SiC-modified cellulose models improve thermal stability, increase thermal conductivity and tensile strength, and reduce polymerization under accelerated thermal ageing. This research offers practical application-relevant improvements in cellulose's thermal-mechanical properties.

Qing-Hua Li et al.,[24] This study investigated the thermal and mechanical properties of an ultrahigh toughness cementitious composite (UHTCC) with hybrid polyvinyl alcohol and steel fibers at elevated temperatures. Results show stable thermal conductivity, flexural strength decreases with temperature, and residual compressive strength increases at 210°C.

G.M. Odegard et al.,[25] In this study a continuum-based elastic micromechanics model is developed for silica nanoparticle/polyimide composites, incorporating molecular structures and interfacial treatments. The model predicts elastic properties for various nanoparticle radii and reveals significant effects on composite properties. The effective interface model predicted elastic properties, which increased with increasing effective particle size.

M.B.A. Shuvho et al.,[26] In this study the Aluminum-based metal matrix composites (AMMCs) offer improved fatigue, creep, wear resistance, high temperature retention, and strength to weight ratio, making them suitable for aerospace and automotive industries. The synthesizes and characterizes Al metal matrix composites with $Al_2O_3$, SiC, and $TiO_2$ particles using stir casting. Mechanical properties increase with SiC, and surface morphology and particle distribution reveal uniform distribution.

S.A. Sajjadi et al.,[27]This study investigated the wettability and distribution of reinforcement particles in aluminum matrix composites (AMCs) using a three-step mixing method. The results show that heat treatment, injection, and stirring improve the nano particles' incorporation and distribution, while increasing hardness, compressive strength, and porosity with increasing weight percentage of nano Al2O3 particles.

Haoming Fang et al.,[28] In this study they studied a graphene-based polymeric composite with polydimethylsiloxane (PDMS) is proposed for effective heat management of electronic devices. The composite improves thermal conductivity, insulativity, and mechanical properties, making it suitable for cooling ceramic heaters. GF-filled elastomer composites improve thermal, mechanical, and electrical properties by modifying 3D graphene through PDA and APTS functionalization. Highly anisotropic, highly mechanical, thermally stable, and insulativity, these composites have promising applications in electronic device heat management.

K X Sin et al.,[29] This study investigated using titanium dioxide as a nanofiller in ethylene propylene diene monomer (EPDM) nanocomposites as thermal insulators. Three filler loadings were used, and thermal and mechanical characteristics were compared. Results showed improvements in thermal performance and tensile strength. The impact of TiO2 nanofiller on EPDM nanocomposites, revealing improved mechanical strength, stiffness, and superior thermal properties.

Abdulrahman Khamaj et al.,[30] In this study they studied the High-energy ball milling and compaction and sintering were used to create a Cu-based hybrid nanocomposite reinforced by $Al_2O_3$ and GNPs. The composite improved mechanical and thermal properties, with a 21%, 16.7%, and 55.2% increase in hardness, thermal conductivity, and CTE. Hybrid Cu-10% $Al_2O_3$/GNPs nanocomposites were produced using high-energy ball milling, and their properties were examined. The optimum GNP content was 0.5%, resulting in improved mechanical properties and thermal conductivity.

Jong Hoon Lee et al.,[31] In this they Investigated the Inorganic silicate nanoplatelets were incorporated into biodegradable poly(l-lactic acid) (PLLA) to improve mechanical stiffness in porous scaffold systems. Modified montmorillonite nanoplatelets increased tensile modulus and biodegradation rate, making this nanotechnology suitable for various scaffold systems. MMT clay nanoplatelets incorporated with PLLA improve scaffold mechanical properties, crystallization characteristics, and biodegradation rate.

A. HAQUE1 et al.,[32] This study investigated the impact of nano clay particles like montmorillonite on improving mechanical and thermal properties of fiber reinforced polymer matrix composites. The results show significant improvements in interlaminar shear strength, flexural strength, and fracture toughness with low loading of organo silicate nanoparticles.

M. Vaghari et al.,[33] In this study, they studied about Al/ $Al_2O_3$ metal-based nanocomposites offer excellent mechanical properties and fatigue performance, making them promising for various applications. A study analyzed the composite's mechanical properties, fatigue performance, and fracture surfaces, revealing that up to 6 wt.% reinforcement increased fatigue strength, while higher reinforcement had a detrimental effect.

Junwen Ren et al.,[34] In this paper they studied about a novel strategy enhances thermal conductivity in epoxy composites using hybrid graphene and boron nitride nanoparticles. This enhances thermal conductivity by about 140%, with high electrical resistivity and low dielectric loss. This study fabricated hybrid nanoparticles with BNNSs on graphene, enhancing thermal conductivity and electrical insulation. The composites showed improved thermal conductivity and dielectric properties, making them potential for thermal management applications in electronic devices.

Elif Bahar et al.,[35] In this paper they studied Polypropylene and cellulose nano whiskers are combined to create nano polymer composites with enhanced mechanical and thermal properties. Maleic anhydride grafted PP improves compatibility, while CNW distribution enhances uniformity. Results show uniform CNW distribution, improved tensile strength, and crystallinity. Further research on surfactants and processing conditions could improve CNW distribution and properties.

K. Rajesh et al.,[36] In this study Titanium dioxide nanoparticles doped PVA/PVP polymer nanocomposites enhance mechanical properties, decrease optical energy gap, and increase tensile strength and Young's modulus. Fluorescence analysis reveals surface roughness and dielectric constant. XRD analysis showed increased crystallinity, mechanical properties, and surface roughness with TiO2 addition. The doping process enhances optical, electrical, mechanical, and dielectric properties, with highest ac and dc conductivities at 12 wt%TiO2.

Akarsh Verma1 et al.,[37] In this study, they studied the Pyrolysis converts waste tires into recyclable products, and this study fabricated and characterized carbonaceous filler-modified epoxy resin composites. The 5 wt% carbon black composite showed the best mechanical properties, making it a potential candidate for automotive polymer coatings. Experimental investigation found 5 wt% carbon black nanofiller reinforced epoxy resin composites with strong interfacial bonds and uniform distribution, enhancing tensile and compressive strengths.

Fatih Yıldırım et al.,[38] This study investigated the thermal and mechanical properties of nanocomposite materials reinforced with Multiwalled Carbon Nano Tube dopped PVA nanofibers. The nanocomposite materials underwent uniaxial tensile tests, comparing their strength, elasticity modulus, and toughness with pure epoxy samples.

Chao-Kai Yang et al.,[39] In this study, they explored multiwalled carbon nanotubes as mechanical reinforcement in epoxy polymer, increasing flow stress, fracture strain, and strengthening composites. Mechanical experiments on nanocomposite with MWNT reinforcements investigated strain rate and MWNT content's impact on deformation flow response and fracture analysis. Fracture analysis revealed catastrophic failure in all tested conditions, with flow stress increasing due to MWNT inhibition.

Harekrushna Sutar et al.,[40] In this study they investigated the mechanical strength and thermal stability of polypropylene (PP) and graphene nanoplatelet (GNP) composites. Thinner GNPs were found to improve dispersion and agglomeration, making them more advantageous for improving polymer properties. Thinner GNPs improved tensile strength, flexural strength, and impact strength. Sheet thickness significantly influenced performance efficiency, with thinner GNPs facilitating overall dispersion and hindering efficient inter-particle contact2.1 IoT sensors in agriculture.

## III. Conclusion

New technologies require materials showing novel properties and/or improved performance compared to conventionally processed components. Because of improved properties of nanocomposite materials, nanocomposites are preferred over composite materials. Different types of nanocomposite materials like polymer matrix, ceramic matrix, aluminium metal matrix, polyethylene boron nitride nanocomposite, and other nanocomposites are studied. The nanomaterials are mostly used in the polymer matrix nanocomposite. Using the graphene nanoplates, ZnO nanoparticles, carbon nanotubes, PVA nanocomposite films, $ZrO_2$ Nanoparticle etc the properties, like mechanical, Thermal, and electrical, hardness, elastic modulus, tensile modulus of elasticity, ultimate strength, flexural strength, stiffness of materials were improved. The nanocomposites exhibit multifunctional properties such as high surface- to volume ratio, high mechanical strength, and high thermal expansion. The nanocomposites were also used because of their lightweight, versatility, and low cost.

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