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An Overview of Nanocomposites and Some Roles in Textile

Md. Alif Robaiyat[1*], Md. Sabbir Ahmed[2], Kazi Takbir Hossain[3], Md Hafijur Rahman Tanvir[4], Md. Istiak Ahammed[5]

[1,2,3,4,5]Studying, B.Sc. in Textile Engineering, Green University of Bangladesh, Bangladesh.*

Email: [2]sabbirrs469@gmail.com, [3]kazitakbir5@gmail.com
[4]mdhafizurrahmantanvir@gmail.com, [5]istiakemon21@gmail.com
Corresponding Email: [1]engr.alif.tex@gmail.com*

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***Abstract:** In this review paper, first of all we discuss about what is nanofluid/nanocomposite. We write some effects of nanofluid like partial concentration, temperature and surfactant effect. Nanomaterials toxicity topic is also added. Then we include the role of nanomaterials in functional textiles and fibers. Then we include various kinds of properties like antibacterial, physical, chemical, mechanical, optical and electrical properties. Also nanofiber designing method, different types of synthesis processes such as electrospinning, muti-jets, mechanical milling, lithography, sputtering, arc discharge, laser ablation, CVD, solvothermal, hydrothermal, sol-gel, reverse micelle method. Then we add ideas about nanocomposite fiber, carbon nanofibers and carbon nanoparticles. Lastly application of nanocomposite and application in textile are discussed. This all points are written by the help of our knowledge and also some research papers, review papers and books. We read and analyze different types of source including nanomaterial, nanocomposite. And also for better understanding we used some figures with proper citations and references. This review paper represents a basic idea of nanocomposites/nanomaterials.*

***Keywords:** Nanocomposites, Nanomaterials, Nanofluids, Textile.*

1. INTRODUCTION

1.1 Nanofluid

Nanofluids are engineered by dispersing nanoparticles into a base fluid, creating a liquid-solid mixture. (Choi, 1995), has revolutionized the approach to enhancing the thermal properties of fluids, leading to significant improvements in heat transfer applications. Influence of Particle Concentration, Temperature, and Surfactant on Nanofluid Surface Tension

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1.2 Effect of Particle Concentration

At higher concentrations of nanoparticles, surface tension generally increases, demonstrating a consistent trend across various base fluids and nanoparticle types. Conversely, at lower concentrations, the surface tension behavior varies based on the base fluid and nanoparticle characteristics. Nonetheless, it is widely accepted that the surface tension of nanofluids tends to increase with the nanoparticle concentration. (Yong Hoon Jeong, 2008)

1.3 Effect of Temperature

Increasing the temperature typically reduces the surface tension of nanofluids. This reduction can be attributed to the enhanced molecular movement at elevated temperatures, which decreases the cohesive forces at the liquid's surface. (S.S. Khaleduzzaman, 2013)

1.4 Effect of Adding Surfactant

Surfactants can significantly influence the surface tension of nanofluids. For instance, in SWNTs/Water nanofluids with NaBDS surfactant, surface tension initially decreases and then stabilizes at certain surfactant concentrations. When SWNTs are added to deionized water with surfactants, the surface tension remains unchanged at low volumes but decreases at higher volumes. Similarly, with n-decane, an Al/surfactant mixture shows a reduction in surface tension as surfactant concentration increases. This trend highlights the complex interplay between surfactants, nanoparticles, and base fluids in modifying surface tension. (Qiao, 2012)

2. RELATED WORKS

2.1 Advances in Nanomaterials and Nanotechnologies

Over the past few decades, the field of nanotechnology has garnered significant attention due to the unique physical, chemical, and biological properties that emerge when materials are scaled down to the nanoscale (<100 nm). These properties, which include a high surface area to volume ratio and quantum effects, fundamentally alter the behavior of materials compared to their bulk counterparts. This section provides an in-depth overview of the size-dependent physical, chemical, electrical, magnetic, and optical properties of nanomaterials, along with a simplified explanation of quantum confinement effects. (Asha, 2020)

2.2 Electrospun Polymer Nanofibers (EPNF)

Electrospun polymer nanofibers represent a crucial class of nanomaterials with diverse applications. This section reviews the desirable features of EPNF, such as their high aspect ratio, surface area, and processability. It covers the various production methods, with a focus on electrospinning, and discusses the parameters influencing the electrospinning process. Detailed insights into the mechanical, electrical, chemical, and optical properties of EPNF are provided, along with their applications in biomedical engineering, sensors, air filtration, protective clothing, and energy devices. (Farooq, 2023)

2.3 Nanotechnology in the Textile Industry

The textile industry has rapidly adopted nanotechnology, leveraging its ability to impart multifunctional properties to fabrics. Applications include enhancing antibacterial properties,

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UV protection and ease of cleaning, water and stain repellency, and odor resistance. This section explores the integration of nanotechnology into textile processing and products, highlighting its potential to improve fabric performance without compromising inherent properties like flexibility and processability. (GOUDA, 2013)

2.4 Development of Polymeric Nanofibers

The demand for polymeric nanofibers has surged due to their potential in various applications, including tissue engineering, drug delivery, protective clothing, and filtration. This section provides a comprehensive review of the methods for producing nanofibers, particularly electrospinning, and it's various derivatives. The advantages and disadvantages of each production process are discussed, along with schematic diagrams illustrating different nanofiber production techniques. (Ibrahim Alghoraibi, 2018)

2.5 Evolution and Applications of Nanomaterials

Nanomaterials, with at least one dimension in the range of 1 to 100 nm, have unique properties due to their high surface areas. This section discusses the history, classification, and synthesis methods of nanomaterials, including top-down and bottom-up approaches. It highlights the distinctive features of nanomaterials and their applications in various fields, such as electronics, catalysis, and biomedical devices. (Nadeem Baig, 2021)

2.6 Nanoparticles in Functional Fibers

Nanoparticles, due to their unique surface properties, offer new functionalities to conventional materials. This section reviews the approaches for integrating nanoparticles like silver, titania, and zinc oxide into synthetic fibers, enhancing properties like antimicrobial activity, UV resistance, and robustness. The potential of electrospinning in creating ultrathin fiber mats with controlled properties for applications like wound healing is also discussed. (Pedro J. Rivero, 2015)

3. Nanomaterial's Toxicity

The widespread use of nanomaterials in consumer products raises concerns about their long-term health effects. Although nanomaterials are increasingly used in electronics, sports equipment, sunscreens, and biomedical applications, their potential toxicity remains under-studied. Regulatory bodies have begun to question whether materials like carbon nanotubes should be treated with caution similar to known carcinogens. Ensuring safe handling of nanomaterials to prevent inhalation and exploring non-inhalation routes of absorption, such as dermal and injectable exposure, is crucial for worker and consumer safety. (Sharifi, 2012)

4. Nanomaterials for Functional Textiles and Fibers

Nanoparticles can add new functionalities to textiles, such as antimicrobial properties, UV protection, and water resistance. Their integration into fabrics can solve traditional issues like microbial growth and flammability. Electrospinning is a promising technique for incorporating nanoparticles into ultrathin fibers, creating materials suitable for wound healing and other applications. This section discusses the integration of nanoparticles into textiles and the potential benefits of such enhancements. (Pedro J. Rivero, 2015)

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5. Properties of Nanocomposites

5.1 Antibacterial Properties

Nanostructured materials with antibacterial properties, such as silver nanoparticles, are increasingly used in textiles to provide antimicrobial protection. Silver is particularly effective against bacteria, viruses, and fungi, making it valuable for applications in food preservation, medical devices, and water treatment. The exact mechanism of silver's antimicrobial action is still debated, but it is believed to involve the release of silver ions and their interaction with microbial cell membranes. (Pedro J. Rivero, 2015)

5.2 Optical Properties

Nanocomposites, such as CdS/PANI hybrid nanocables, exhibit enhanced optical properties due to increased carrier concentrations and improved photoluminescence. Conducting polymers in one-dimensional electrospun systems can significantly boost the photoluminesce nce intensity of semiconductors, making these composites promising for various optical applications. (Xiaofeng Lu, 2011)

5.3 Physical Properties

Nanomaterials can be categorized based on their dimensions: zero-dimensional (clusters and particles), one-dimensional (nanotubes and nanowires), two-dimensional (nanoplates and layers), and three-dimensional (nanowire and nanotube arrays). These structures can exist in various forms, including single, fused, aggregated, or agglomerated, with diverse shapes such as spherical, tubular, ellipsoidal, and irregular. (Asha, 2020)

5.4 Chemical Properties

The arrangement of atoms in a crystal lattice, represented by its unit cell, is crucial for understanding the chemical properties of nanomaterials. Fullerenes, for example, consist of 60 carbon atoms arranged in a spherical structure with unique bond lengths, influencing their chemical reactivity. This section explores the chemical properties of nanomaterials, including their bonding and interaction with other substances. (Asha, 2020)

Nanomaterials offer vast potential for enhancing material properties and developing new applications. However, further research is needed to understand the long-term health effects of nanomaterial exposure. Establishing protective measures and regulatory guidelines is essential to ensure the safe handling and usage of nanomaterials. (Sharifi, 2012)

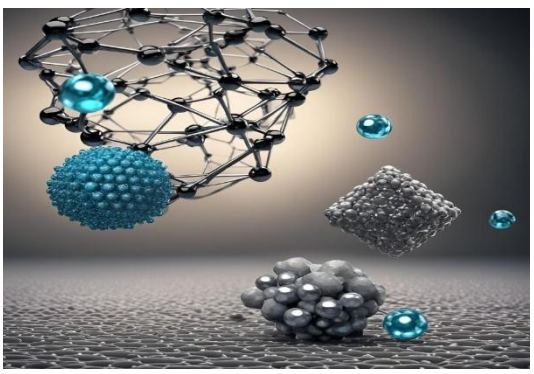


Fig1: Carbon allotropes.

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5.5 Electrical Properties

Electrical properties, such as conductivity and resistivity, are fundamental characteristics that define the performance of materials, particularly at the nanoscale. Similar to optical and magnetic properties, electrical properties exhibit significant changes when the material dimensions are reduced to the nanometer scale. This size reduction induces the quantum-size effect and quantum confinement, which significantly alter the behavior of charge carriers. At the nanoscale, electron energy levels become quantized, leading to unique electrical phenomena.

For instance, certain conductive metal nanoparticles, like copper, can transition to a nonconductive state under specific voltages when their size is reduced to a few nanometers. This is due to the quantum confinement effect which alters the energy distribution of electrons. Conversely, materials traditionally known for their insulating properties, such as silicon dioxide, can lose their insulation and become conductive when scaled down to nanometer dimensions. This inversion of properties underscores the complexity and novelty of nanoscale materials.

Moreover, reducing the size of materials often enhances crystalline perfection and reduces defects, which in turn decreases defect scattering. This reduction in defect scattering lowers resistivity and increases conductivity, making nanoscale materials potentially more efficient conductors. (Asha, 2020)

5.6 Mechanical Properties

The mechanical properties of nanomaterials are influenced by several interrelated factors: nanoparticle selection, fabrication process, grain size, and grain boundary structure. These factors interact in complex ways to determine the mechanical performance of nanomaterials. The choice of nanoparticles affects the intrinsic mechanical characteristics, while the fabrication process influences the overall structural integrity and quality. Grain size and boundaries play crucial roles in defining properties like strength, ductility, and toughness. (Qiong Wu, 2020)

6. Different Methods for Nanofiber Design and Fabrication

Numerous methods exist for the design and fabrication of nanofibers, each with unique advantages and applications. These methods include the STEP (solvent, temperature, evaporation, pressure) method, phase separation, self-assembly, template synthesis, and freeze-drying. Among these, electrospinning is particularly noted for its effectiveness in producing nanofibers with various structures, such as core-shell, bicomponent, hollow, and porous configurations.

For instance, core-sheath structures can be produced using coaxial electrospinning, while hollow nanofibers can be fabricated through chemical vapor deposition (CVD), electrospinning, or direct coaxial spinning. Porous nanofibers are often produced via phase separation methods. Electrospinning, also known as electrostatic spinning, remains the most widely used technique for nanofiber production due to its versatility and efficiency. (Farooq, 2023; Ibrahim Alghoraibi, 2018)

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6.1 Design Modifications in Electrospinning Setup

Over the past two decades, the traditional electrospinning technique has evolved significantly, giving rise to numerous derivative methods. These include multi-jet electrospinning, needleless electrospinning, bubble electrospinning, electro-blowing, cylindrical porous hollow tube electrospinning, melt electrospinning, coaxial electrospinning, force spinning, flash-spinning, self-bundling electrospinning, nano spider electrospinning, and charge injection electrospinni ng. Such innovations have enhanced the versatility and efficiency of electrospinning, enabling the creation of diverse nanofiber structures with tailored properties. (Ibrahim Alghoraibi, 2018)

7. Synthesis of Nanocomposites

7.1 Electrospinning Using Porous Hollow Tubes

This method involves pouring a polymer solution into a cylindrical tube with porous walls, creating fibers from multiple jets. Under a pressure of less than 10 kPa, the polymer is forced through the pores and onto the tube's exterior. Each pore acts as a nozzle, producing individual jets that ultimately form electrospun fibers. This multi-jet electrospinning technique enhances production rate and uniformity, making it suitable for large-scale nanofiber fabrication. (Ibrahim Alghoraibi, 2018)

7.2 Multi-jet Electrospinning from Multiple Needles

Multi-needle electrospinning is a straightforward and efficient technique for fabricating composite fibers from polymers that are difficult to dissolve in common solvents. The configuration of the needles, including their number and gauge, is crucial. The spacing between needles depends on the nozzle gauge and the properties of the polymer solution. This method allows for the simultaneous production of multiple fibers, improving productivity and enabling the creation of complex nanofiber composites. (Ibrahim Alghoraibi, 2018)

7.3 Melt Electrospinning

Melt electrospinning is an environmentally friendly alternative to solution electrospinning, as it does not require solvents. This method can be performed on a standard laboratory bench without the need for ventilation equipment like fume hoods. Melt electrospinning is particularly suitable for polymers with high melting points, enabling the production of fibers with unique mechanical and thermal properties. (Prof. Dietmar W. Hutmacher, 2010)

Fig2: Melt electrospinning.



Another clear difference between solution electrospinning and melt electrospinning lies in the handling of the polymer medium. Unlike solution electrospinning, where a fluid line can be

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used to transport the polymer solution, melt electrospinning requires direct alignment of the plunging system with the syringe to prevent the polymer melt from cooling and solidifying prematurely. This necessity arises because fluid lines would cause the polymer melt to harden before reaching the spinneret (refer to Figure 1). Consequently, the electrospinning device's height can become quite substantial, which makes horizontally oriented systems more practical for standard laboratory setups, as they can be managed on a conventional bench.

Despite this, certain applications demand a vertical setup. For instance, vertical systems are essential for direct in vitro electrospinning, where the process involves liquid environments such as cell cultures. In such cases, horizontal setups would be impractical due to the risk of spilling liquids and compromising sterility when Petri dishes are tilted.

The equipment used for melt electrospinning also varies. While syringe pumps are common in solution electrospinning, they are not always suitable for melt electrospinning. An alternative approach, as demonstrated by Long and colleagues, involves using an air pressure system to extrude the polymer melt from the spinneret. Another innovative method employed by the Ogata group uses a solid polymer filament that is mechanically pushed out of the device. Additionally, a recent advancement in the field includes the use of line laser melt electrospinning, which enables the creation of multiple Taylor cones from polymer sheets, showcasing the diverse techniques being developed to enhance the versatility and efficiency of melt electrospinning. (Prof. Dietmar W. Hutmacher, 2010)

These advancements in melt electrospinning technology reflect ongoing efforts to optimize the process for various applications, highlighting the importance of equipment configuration and operational flexibility. As research continues, the development of more sophisticated and adaptable melt electrospinning systems is likely to further expand the potential of this technique in creating high-quality nanofibers for a wide range of scientific and industrial applications.

7.4 Mechanical Milling

Mechanical milling emerges as a highly efficient technique capable of transforming bulk materials into nanoscale counterparts, offering significant utility in the fabrication of nanocomposites. Its effectiveness extends to the production of a diverse array of materials, including oxide- and carbide-strengthened aluminum alloys, as well as wear-resistant spray coatings. Moreover, mechanical milling plays a pivotal role in the synthesis of complex composite structures like aluminum/nickel/magnesium/copper-based alloys. By employing

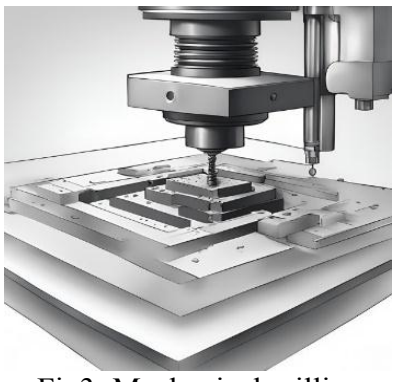


Fig3: Mechanical milling.

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controlled mechanical forces, this method enables the refinement of material structures down to the nanometer scale, facilitating the enhancement of material properties and functionality. Through its versatility and precision, mechanical milling continues to drive advancements in materials science and engineering, opening new avenues for the development of advanced materials with tailored properties and applications. (Nadeem Baig, 2021)

7.5 Electrospinning

Electrospinning stands out as a versatile process for the production of nanofibers from various materials, predominantly polymers. This technique finds widespread application in the creation of hollow polymer structures, core-shell configurations, as well as organic, inorganic, and hybrid materials. Notably, coaxial electrospinning represents a significant advancement in this field, involving the use of two coaxial capillaries to produce ultrathin fibers on a large scale. These ultrathin nanomaterials can extend over several centimeters, offering immense potential for diverse applications across various industries. (Nadeem Baig, 2021)

7.6 Lithography

Lithography emerges as a powerful tool for sculpting nano architectures using either beams of light or electrons. This technique can be categorized into two main types: masked lithography and maskless lithography. Masked lithography utilizes large surface areas to transfer nanopatterns using masks, encompassing methods such as photolithography, nanoimprint lithography, and soft lithography. Conversely, maskless lithography enables the direct transfer of arbitrary nanopatterns onto large surface areas without the use of masks. The versatility of lithography enables precise control over nanostructures, facilitating the development of intricate and tailored materials for various applications. (Nadeem Baig, 2021)

7.7 Sputtering

Sputtering presents an effective approach for producing nanocomposites by bombarding solid surfaces with high-energy particles, typically plasma or gases. This method is particularly renowned for generating thin-film nanomaterials with uniform compositions and minimal impurities. Various techniques, including magnetron, radio-frequency diode, and DC diode sputtering, can be employed to achieve specific material properties. Sputtering offers a cost-effective alternative to electron lithography while maintaining high material purity, making it a preferred choice in many fabrication processes. (Nadeem Baig, 2021)

8. METHODOLOGY

8.1 The Arc Discharge Method

The arc discharge method is instrumental in the production of diverse nanostructured materials, particularly carbon-based materials like carbon nanotubes and nanohorns. This method involves adjusting two graphite rods within a chamber under controlled helium pressure. The absence of oxygen and moisture within the chamber facilitates the formation of carbon nanostructures, including grapheme nanostructures under optimized conditions. The arc discharge method holds promise for the synthesis of advanced carbon-based materials with tailored properties for various applications. (Nadeem Baig, 2021)

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8.2 Laser Ablation

Laser ablation is a versatile synthesis technique that involves the generation of nanoparticles by irradiating a target material with a powerful laser beam. This method enables the production of a wide range of nanocomposites, including metal nanoparticles, carbon nanoparticles, oxides, and ceramics. Laser ablation offers precise control over particle size and composition, making it a valuable tool for engineering advanced materials with tailored properties for specific applications. (Nadeem Baig, 2021)

8.3 Bottom-Up Approaches: Chemical Vapor Deposition (CVD)

Chemical vapor deposition (CVD) plays a pivotal role in the generation of carbon-based nanomaterials, offering a high degree of control over material properties and structure. In this method, thin films are formed on substrate surfaces through the chemical reaction of vapor-phase precursors. CVD is renowned for producing high-quality nanocomposites, including carbon nanotubes, under optimized conditions. The precise manipulation of precursor gases and reaction parameters enables the synthesis of two-dimensional nanostructures with tailored properties for diverse applications. (Nadeem Baig, 2021)

8.4 Solvothermal and Hydrothermal Methods

Solvothermal and hydrothermal methods represent prominent approaches for producing nanomaterials through heterogeneous reactions in aqueous or nonaqueous media, respectively. These methods are conducted in closed systems and are particularly well-suited for the synthesis of nanowires, nanorods, nanosheets, and nanospheres. Solvothermal and hydrothermal methods offer versatility and scalability, making them indispensable tools for engineering advanced nanostructures with tailored properties for various applications. (Nadeem Baig, 2021)

8.5 The Sol-Gel Method

The sol-gel method is a widely used wet chemical technique for synthesizing nanomaterials, particularly high-quality metal oxide-based materials. This method involves the transformation of liquid precursors into sols, which are then converted into gels. The controlled congelation of nanoparticles within the sol-gel system enables the fabrication of homogeneous materials with tailored properties. The sol-gel process offers numerous advantages, including low processing temperatures, homogeneous material synthesis, and the ability to produce complex nanostructures with precise control over composition and morphology. (Nadeem Baig, 2021)

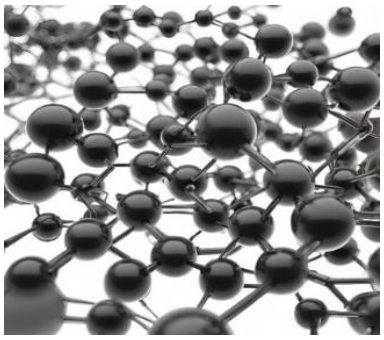


Fig4: Sol–Gel synthesis

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8.6 Reverse Micelle Methods

Reverse micelle methods present a unique approach to tailoring nanomaterials with precise characteristics in terms of shape and size. Unlike conventional methods, reverse micelle techniques involve the formation of micelles in a water-in-oil emulsion, where the hydrophilic heads of surfactant molecules are directed towards a core containing water droplets. This core serves as a confined nanoreactor for nanoparticle synthesis, providing an ideal environment for controlled particle formation. By adjusting parameters such as the water-to-surfactant ratio, the size of these nanoreactors can be finely tuned, thereby influencing the size of the nanoparticles produced. Consequently, reverse micelle methods offer a straightforward pathway to synthesizing nanoparticles with uniform sizes and shapes. The resulting nanoparticles exhibit exceptional uniformity and monodispersity, making them highly desirable for a wide range of applications across various industries. (Nadeem Baig, 2021)

9. Nanocomposite Fiber

Nanocomposite fibers represent a fascinating realm of materials science, combining the best attributes of different components to achieve superior properties. These composites, composed of at least one component, aim to capitalize on the unique characteristics of each constituent material. They encompass a diverse array of architectures blending one, two, or three-dimensional materials with amorphous components at the nanoscale. Widely utilized in automotive, aerospace, and military applications, nanocomposite fibers are produced by dispersing nanoscale fillers into a fiber matrix. The high surface area and aspect ratio of these fillers facilitate interactions with polymer chains, thereby enhancing the composite's mechanical properties. Common nanofillers include nanosilicates, metal oxide nanoparticles, graphite nanofibers (GNF), and single-wall and multi-wall carbon nanotubes (CNTs). Notably, novel composite materials reinforced with CNTs have emerged, offering unparalleled strength, lightweight properties, and high electrical conductivity. (GOUDA, 2013)

10 Carbon Nanofibers and Carbon Nanoparticles

Among the myriad of nanoscale filler materials, carbon nanofibers and carbon black nanoparticles stand out for their remarkable properties and versatile applications. Characterized by diameters less than 1 mm or 1000 nm, carbon nanofibers boast a high surface area-to-volume ratio and exhibit small pore sizes in their fibrous structure. These nanofibers effectively reinforce composite fibers, thanks to their high aspect ratio, while carbon black nanoparticles contribute to improved abrasion resistance and durability. Researchers have explored various fiber-forming polymers, such as polyester, nylon, and polyethylene, incorporating nanofillers at loadings ranging from 5 to 20%. The applications of nanofibers are diverse, ranging from filtration devices to wound dressings, owing to their ability to trap viruses and spore-forming bacteria. Moreover, the development of protective garments made from nanofiber materials holds promise for applications in healthcare, firefighting, emergency services, and military operations, offering enhanced safety and protection. (GOUDA, 2013)

11. Application of Nanocomposites

Nanotechnology has revolutionized the textile industry, enhancing fabric durability, comfort, cleanliness, and reducing production costs. By integrating nanotechnology into textiles,

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numerous benefits are realized, including improved economy, energy efficiency, environmental friendliness, and controlled substance release. Textile materials serve as ideal substrates for nanoparticle incorporation due to their large interfacial area per unit weight or volume. Nanoparticles embedded in textiles endow finished fabrics with diverse functional properties, such as antibacterial, UV protection, easy cleaning, and water and stain resistance, and anti-odor characteristics. This integration of nanotechnology with textiles has found applications across various sectors, including sports, skincare, space technology, and clothing, enabling the development of multifunctional materials and fabrics with unique capabilities. (GOUDA, 2013)

11.1 Flame Retardant Application

Polyamide and polyester, common synthetic fibers, are highly flammable, necessitating the development of flame retardant products to meet regulatory standards. Traditional flame retardant systems often contain halogen-based additives; however, new regulations favor halogen-free compounds, particularly phosphorus-based systems, as effective alternatives in the textile industry. These phosphorus-based systems show promise for enhancing fire safety in textiles while minimizing environmental impact. (Ibrahim Alghoraibi, 2018)

12. RESULT AND DISCUSSION

This paper provides comprehensive insights into nanocomposites/nanofluids, elucidating their key properties, effects, synthesis processes, and applications across various fields, including textile engineering. The knowledge gained from this study serves as a valuable foundation for further research endeavors and academic advancement in the field of nanotechnology.

13. CONCLUSION

Nanomaterials represent a burgeoning field with immense potential for future applications. Researchers continue to explore the diverse possibilities offered by nanotechnology, including the development of nanobots for cell repair, which holds promise for revolutionizing medical treatments. Nanocomposites offer viable solutions to emerging scientific and technological challenges, with ongoing efforts focused on addressing processing challenges and optimizing performance. With growing market demand across industries, nanocomposites remain at the forefront of materials innovation, outperforming traditional materials in various applications.

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