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Nanocellulose in Metals: Advancing Sustainable Practices in Metal Refining and Extraction Processes

Pavankumar R. Sonawane[1], Deepak M. Deshmukh[2], Vedant A. Utikar[3], Shraddha S. Jadhav[3] and G. A. Deshpande[1]

[1]*Associate Professor, JSPM's Rajarshi Shahu College of Engineering, Tathawade, Pune - 411033, Maharashtra; coordinator.design@gmail.com, girijadeshpande2@gmail.com*
[2]*Assistant Professor, Pravara Rural Engineering College, Loni - 413736, Maharashtra; deshmukhdm@gmail.com*
[3]*Student, JSPM's Rajarshi Shahu College of Engineering, Tathawade, Pune - 411033, Maharashtra; vutikar@gmail.com, shraddhasj10@gmail.com*

Abstract

The military can put nanocellulose to good use by developing self-repairing and self-diagnosing materials. Nanocellulose is eight times stronger than stainless steel and has ten times the strength of Kevlar. The use of nanocelluloses in the armed forces is the primary topic of this study. Several studies have shown that the military can successfully use nanocellulose as a new green bio-based material; however, the technology still needs some refinement. It must be put to the test with authentic chemical weapons like tabun. The economic viability and accessibility of nanocellulose at an industrial scale is another problem. Natural fibers are abundant, providing the armor industry with a low-cost option for meeting the rising demand in the market. However, the NIJ Tier III standard requires that a plate of armor withstand six shots before failing, and this particular type of natural fiber-based hard-shell armor has only been tested for one. Therefore, to make armor plates economically feasible, substantial research is required to increase the ballistic performance of multi-layered armor based on natural fibers. None of the numerous review papers on bio-composites that focus largely on their characterization, production, processing, and other uses have investigated the mechanical endurance of body armor systems.

Keywords: *Bio-Based Material, Kevlar, Mechanical Performanc, Military, Nanocellulose, Natural Fiber*

1.0 Introduction

With an estimated total of $1917 billion, the global military budget in 2019 was up 3.6% over the previous year. The overall expenditure is used for more than just the production of various weapons; it also pays for a significant share of the development of both the uniforms and the weapons. Experts estimate that the United States, Japan, Germany, and Turkey have spent hundreds of billions of dollars on technological development and research. Realizing functionality with the least weight and space is necessary since military power elements are frequently confined by weight, transmission speed, or both. Newer research is progressing quickly to provide the same level of safety. Another method for reducing bulk and weight is to use materials that serve more than one function[1]. (Example: foundation and covert capabilities). Self-healing and self-diagnosing materials are potential solutions to these issues since they may boost system resilience while reducing maintenance requirements.

**Author for correspondence*

Nanocellulose is a substance that can be used in military applications. A nanoscale version of cellulose is the source of this substance. When compared to Kevlar, nanocellulose is eight times stronger than stainless steel when tested for tensile strength. Military applications of nanocellulose are the exclusive topic of this study. A scientific investigation like this will ensure the reliability of the cutting-edge electronics that underpin many uses. Nanocellulose may be the best candidate among the materials mentioned earlier for fulfilling these needs. A great deal ofresearch is still needed before nanocellulose is used in any commercial setting, but it can be altered and functionalized for various applications. When those nano cells are densely packed together, the benefits of cellulose become much more substantial. It might produce highly ordered regions from which nanomaterials known as nanocelluloses could be extracted[1,2]. Two distinct types of nanocellulose exist nanostructured materials and nanofibers. The origins of the cellulose, the conditions under which it was extracted and manufactured, and any treatments applied before or after that all influence the structure, size, and other features of each type. Nanocellulose's unique 3-D organizational nanostructure and nanoscale physicaland chemical characteristics open up exciting new avenues for research and development[3].

Nanocellulose has the potential to significantly impact the mining, fuels, minerals, metallurgical, and metal sectors in addition to its uses in military-related domains. Applications for nanocellulose include fuel extraction and processing, metal refining, and the extraction and processing of minerals. Its special qualities include high strength, low weight, and biocompatibility. For example, the mechanical characteristics of components in mining equipment can be enhanced by the use of nanocellulose-reinforced composites, increasing their efficiency and longevity.

Additionally, the creation of environmentally acceptable and sustainable materials for use in metallurgical processes may benefit from the usage of nanocellulose. The use of nanocellulose may provide creative solutions for the material performance and environmental impact issues that the mining and metallurgical sectors frequently encounter. Studies can investigate the application of nanocellulose in fuel extraction, different metallurgical processes, and core and non-core mining activities to improve productivity, lessen environmental effect, and support the long-term viability of these sectors.

Packaging, automotive, energy, and other industries are just a few of the many that have shown interest in using nanocellulose, which has gained a reputation as a reliable material. These advances in nanocellulose technology have potential military uses, both on their own and as part of composite and other materials. However, the newly produced material must maintain or improve upon the qualities of the materials now used in the fabrication of military applications. For this reason, we have reviewed the current and future uses of nanocellulose in the defense sector. The paper also sheds light on nanocellulose's contribution to the enhanced final qualities of the material now seeing the military application[3].

Nanocellulose, made from a wide variety of natural materials and processed in a number of different ways, has been the subject of intense study over the last two decades. There are still a number of obstacles to be cleared, particularly in the areas of top- and bottom-heavy changes, the advancement of environmentally benign extraction operations at lower costs with fewer energy-consuming procedures, and the scaling up of production. There are gaps between small-scale and large-scale or economic manufacturing that need to be researched further[4]. In addition to its use in the military for things like bulletproof vests and flame-retardant clothing, nanocellulose is finding its way into the textile business, the electrical sector, and even energy applications. High-value fiber byproducts from industry, forests, and farms might be used to synthesis it. Numerous studies have demonstrated that nanoparticles may be utilized in the military as a sustainable bio-based fabric, while further research is still required. Research and Development (R&D) should ideally include real-world application of military technology to guarantee that the features created fulfill military needs.

Nanocellulose is a nanostructured type of cellulose. It's also one of the most effective eco-friendly materials of our day. Interest in nanocellulose (NC) materials has increased because of their recent breakthroughs in mechanical characteristics, sustainability, and nanocomposites, as well as their high viewpoint and quantity[5,6]. Nanocellulose stands out for its superior properties, including its increased surface area, tail or surface chemical ability, higher mechanical capabilities, and anisotropic structure, which raises the possibility that it might be a completely green nanomaterial[6]. It's a fantastic material with promising new uses in a broad range of fields, including healthcare and materials research. Many industries that utilise complex materials might benefit from new applications and enhanced versions of existing ones[7]. Agricultural and forestry waste fibers that are converted into high-value goods may be used to create nanocellulose. Its magnetic features include a low heat conductivity, a high aspect ratio, and a high crystallinity. In this article, we'll take a look at nanocellulose and discuss its promising chemical and physical properties as well as its potential future military uses[8].

There is a lot of room for innovation in the field of nanocellulose's military uses. Multiple works may attest to the usefulness, yet it is always possible to do better. For instance, common biological warfare poisons like sarin and tabun must be used to determine how effectively an antibiotic drug performs. The widespread availability and inexpensive price of nanocellulose at industrial scales can pose problems. NFRPCs, or natural fiber-reinforced polymer composites, have several applications in the building and industrial sectors. They have the potential to be used as major structural components in ballistic and defense applications, among other high-level uses. The use of natural fibers in body armor to improve ballistic performance has largely supplanted the use of synthetic materials like Aramid and Kevlar. With synthetic materials readily available, this sector can meet the rising need for reasonably priced protective gear. These environmentally responsible options would make it easier, cheaper, and safer for military personnel to use armor technology, resulting in fewer casualties[9].

2.0 Materials and Methods

2.1 Nanocellulose Properties, Categorization, and Modification

Nanocellulose is a kind of cellulose that is 100 nm or smaller in size. High impact strength, electrical characteristics, low weight, chemical stability and toxicity, and biocompatibility are only a few of its impressive features. It also has a large specific area, high porosity, and considerable pore interconnectivity. Based on cellulose's hydroxyl groups (-OH), nanocellulose may be easily derivatized and have new functions introduced that are useful in many contexts[10]. Hydroxyl groups comprise cellulose's chemical structure (Figure 1a)[11]. All of these special qualities of nanocellulose is highlighted in Table 1[12]. Nanocellulose may come in three distinct forms: cellulose nanofibers (CNF), cellulose nanocrystals (CNC), andbacterial nanocellulose (BNC). Nanocellulose may be found in various shapes and sizes, but all are nanoscale materials. Figure 1 depicts the CNC, CNF, and BNC topologies that result from many different approaches (b). The other two, CNC and CNF, are derived from plants, while BNC is based on micro-bacterial nanocellulose. CNC and CNF are derived from plants, and their production requires hydrolysis of the plant cellulose in one of three ways: mechanically, physically, or chemically. BNC, on the other hand, is produced through the use of microorganisms and biotechnology. This process produces hydrogels with properties similar to CNF and CNC, including high purity, mechanical strength, and an interconnected micropore system.

This cutting-edge technology paves the way for the process-controlled production of various forms, sizes, surface properties, and nanonetwork topologies. The newly created layered materials have several potential applications, including medicine and defense[13]. Klemm and his co-workers demonstrated the potential for

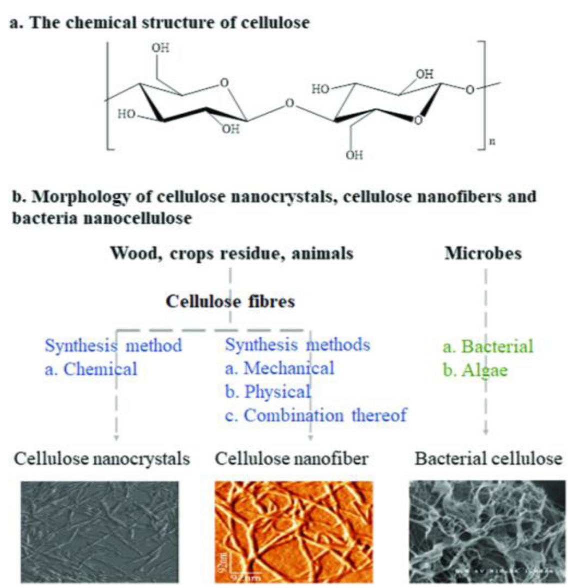

Figure 1. (a) The cellulose composition, (b) morphology of bacterial nanocellulose, cellulose nanofibers, and nanocrystals.[11]

Table 1. Characteristics of nanocellulose[12]

Attribute	Benefits
Renewable	Employing biofuels made from sugarcane waste, palm oil production, bamboo shoots, and wheat products is possible.
Biodegradability	This chemical is commonly known to be biodegradable; it is harmless to the environment, and bacteria may break it down.
Reusable/ Reversibility	The capacity to repeatedly desorb or adsorb contaminants.
High Mechanical and crystalline properties	Influences a material's final properties, especially composites.
High Specific surface area	Since it influences adsorption and response processes, it is one of the most important criteria for nanomaterials.
Surface Functionalization	Nanocellulose compatibility is raised via surface functionalization. It also intends to expand its utility by combining it with other substances such as superconductors, antimicrobials, and fire retardants.

using this technique to develop medicines and medical supplies for cardiology and intestinal surgery. Through this process, it can adapt its behavior and features to meet the needs of different settings. Oxidative stress, carboxylation, dehydrogenation, acylation, subsequent positioning, and polymer bonding are all examples of surface functionalization processes that may be used to achieve this goal[14]. Surface carboxylation is often used to improve nanocellulose's chemical characteristics.

Nanocellulose's surface characteristics and interfacial compatibility are critical to its performance indicators. Increasing the efficacy of nanocomposites necessitates a continuous diffusion of nanocellulose in polymeric composites. How well nanocellulose disperses depends on the balance between charge antagonismand hydrophobic interactions. The dispersibility of nanocellulose may be greatly enhanced by making the necessary changes, such as those indicated above. According to Chu *et al.*, the benefits of hybrids using synthesized nanocellulose outweigh the costs and problems. So, additional research is needed to understand the mechanics of nanocellulose dispersion properly. Figure 2 shows

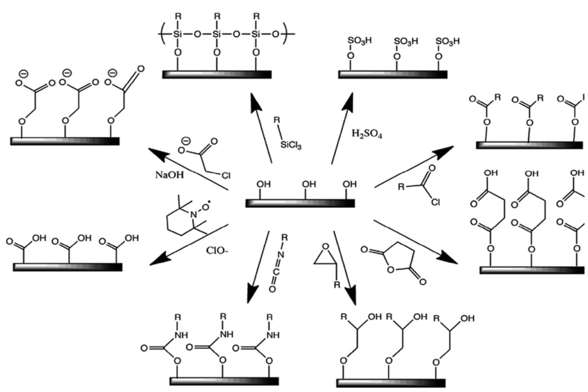

Figure 2. Common surface functionalization on nanocellulose[15].

a variety of nanocellulose surface functionalization techniques.

Furthermore, a survey was done for the term "functionalization of nanocellulose," it was observed that the number of articles/research papers based on the functionalization of nanocellulose has increased in recent years. As a result, scientists' interest in the synthesis process of nanocellulose has grown during the last decade.

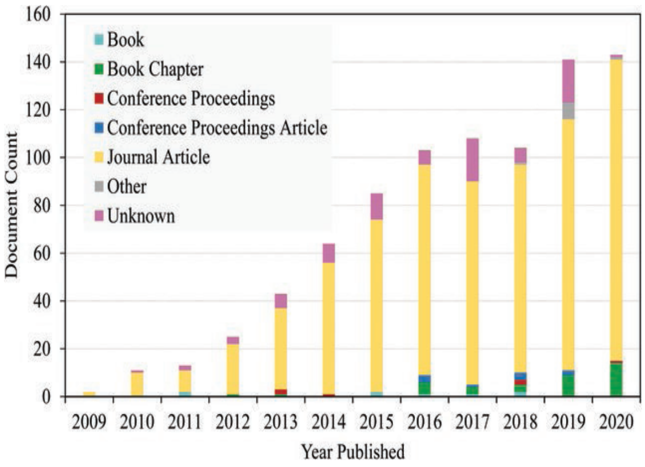

Figure 3. A summary of articles that have been published and focus on the functionalization of nanocellulose.

3.0 Discussion on Applications of Nano Cellulose in Military

3.1 Packaging Sector

Nanocellulose has been the focus of numerous research initiatives because of its potential to be used as a component in different packaging materials. According to the introduction, packaging that satisfies military standards for materials that promote defence and durability, environmental acceptability, and flexibility can be made with nanocellulose[15,16]. Military packaging materials must have certain mechanical qualities. Nanocellulose has been demonstrated to enhance the mechanical properties of packing materials[17]. The mechanical performance of well-known packaging polyolefins including polyethylene, polypropylene, and polyethylene terephthalate may be significantly improved by adding a tiny amount of nanocellulose, often between 1 and 5%. The mechanical characteristics of composites treated with nanocellulose are summarised in Table 2.

3.2 Energy Devices

For its unique reasons, nanocellulose is a promising material for Electrochemical Energy Storage devices (EES). Nanocellulose's unique features, especially its strong electrochemical capabilities, make it a promising

Table 2. Mechanical properties of nanocellulose reinforced composites

Polymer Matrix	Nanocellulose Mixture	Improvement in Mechanical Properties
Polypropylene	2.08 wt.%	σ_t – 34.201 %, E – 175.901% σ_f – 27.81 % E_{flex} – 88.92 %
Polyethylene	3.20 wt.%	σ_t – 57.71 %, E – 92.71 % σ_f – 198.202 % E_{flex} – 25.005 %
Polyvinyl alcohol/starch	10.5% (v/v)	σ_t – 85.201% while elongation at break decreased
Polyamine/ Epoxy resin	0.75 wt.%	σ_t – 29.902 %, E – 66.703% σ_f – 30.603 % E_{flex} – 21.404 %
Poly (styrene-co-butyl acrylate) copolymer	10 wt.%	E – 6142.01 %, σ_t – 104.2 % and elongation at break decreased.
Polycaprolactone	3 – 12 wt.%	Little increase in strain at break and tensile modulus while maintaining tensile strength

σ_t – Tensile Strength; σ_f – Flexural Strength; E – Young's Modulus; E_{flex} – Flexural Modulus candidate for use in cutting-edge energy technology. Nanocellulose's mechanical qualities may be used effectively as a structural matrix in polymer electrolyte composites[18]. Nanocellulose's outstanding interwoven structure also makes it a useful scaffold for building electrode hosts, which improves ion transport and, in turn, the performance of the electrode cycle. Nanocellulose must be functionalized with conductive polymers, metal atoms, or carbon compounds like graphene, soot, and carbon nanotubes because it is not electrically conductive naturally. The improved nanocellulose-based EES has the potential for use in military applications because of its adaptability, low weight, and durability. In addition, the military has shown much enthusiasm for rechargeable gadget technologies[19]. Nanocellulose is used in various energy storage (EES) technologies, such as ultracapacitors, solar cells, and devices to recharge lithium-ion batteries. Nanocellulose has found several uses in military energy applications, including lithium-ion batteries, solar panels, and energy storage systems.

3.3 Fire Retardant Material

Increased utilization of nanocellulose blends that are fire retardant or flame resistant is seen in cutting-edge industries. Nanocellulose-reinforced thermoset nanocomposites were investigated for their fascinating flammability properties. Nanocellulose composites do well during fire tests, giving off less smoke and potentially harmful compounds. New military hardware, buildings, and ecosystems are all saved, and most significantly, lives are saved thanks to their efforts to put out fires. Nanocellulose composites include fire-resistant fillers and additives such as halogen, oxalic acid, iron, mineral deposits, and micro- and nano-compounds to prevent or lessen the effects of a fire[20]. Nanocellulose may be treated with flame retardants: solution impregnation and surface treatment. Nanocellulose composites were sometimes combined with polyurethane to create fireproof materials.

3.4 Propellant

Nanocellulose may create military propellants with a larger energy density per mass than conventional incendiary devices. The functionalization of nanocellulose is essential for its use as a propulsion system. Numerous research efforts and innovations have been dedicated to creating nanocelluloseas a fuel. By using nanocellulose, Zhang *et al*. created a dual solid-based propellant[21,22]. As double-base propellants, they perform very well because of their hydrophilic nature, high aspect ratio, and improved suspension stability compared to traditional double-base propellants. The breaking strengths under tension and elongation rose by around 34% and 45%, respectively. A drop in pressure coefficient of 20% was achieved,while a boost in the propellant burning rate of 27.5% was achieved[23].

3.5 Military Medical

Nanocellulose is already used in medicinal applications, including bioengineering, bone scaffolding, tissue repair, and drug research. Figure 4. Nevertheless, only military-related applications were addressed in this area[24].

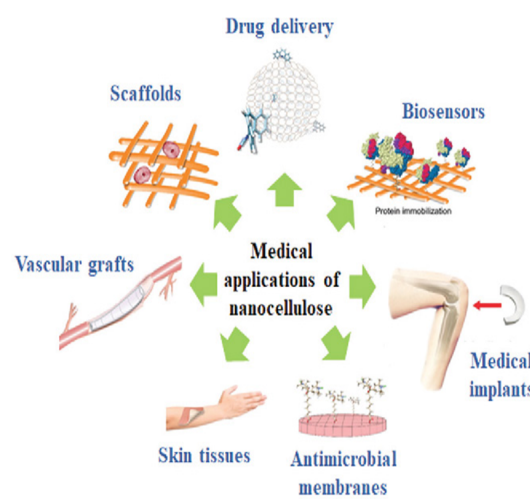

Figure 4. Medical applications of nanocellulose.

3.5.1 Classification of Natural Fibers and Manufacturing Techniques

Natural fibres' exceptional properties are seen in a wide range of industries. Because of their better mechanical qualities and biodegradability, natural fibres are becoming more and more popular, particularly in the automotive industry and for simpler applications. Furthermore, several academics emphasize the need for recycled materials in their investigations. The plastics sector has greatly benefited from the increased interest in

Table 3. Physical and mechanical performance of natural fiber vs. synthetic fiber.

Fibers	Density (g/cm^3)	Tensile Strength (MPa)	Elongation (%)	Tensile Modulus (GPa)
Sugar Palm	1.4	160.01	8.01	4.96
Bagasse	2.0	305	-	17
Bamboo	1.3	135-250	-	11-17
Flax	0.8-1.4	400-1090	2.5-3.7	27.6
Jute	1.8	395-780	1.4-2.1	26.5
Kenaf	1.9	245.5	1.7	53
Aramid	1.9	3000-3250	3.25-3.84	63-67
Kevlar	2.54	3400	2.45-3.82	60

developing new and better materials brought about by the expanding need for technical components. Traditionally, the thermoplastics industry has employed natural materials primarily to reinforce ecological composite products. Natural fibers are quickly gaining popularity for several reasons, including their superior sustainability, eco-friendliness, and renewable resource potential compared to low-cost microfiber-reinforced plastics. As a bonus, reinforced composite compounds made from basic architectural polymers have found widespread usage in several industrial settings. These fibers have a unique cell wall structure that is triangulated into three sections. The position and angle of the small fibrils within the cell wall regulate the fibrous properties. The cell wall comprises two layers: the primary (S1) and the auxiliary (S2). Throughout a plant's life, the primary cell wall continues to spread. There are three distinct layers to the auxiliary cell wall, and a string of microfibrils is inside each. Hemicellulose molecules, net-like in form and substance, adhere to cellulose strands. Lignin and pectin provide adhesion, whereas cellulose and hemicelluloses form a network[29,30] Cellulosic fibers' strength and rigidity come from their adhesive qualities. How well fibers retain their engineering qualities over time is a function of their secondary layer (S2). For example, increasing the amount of cellulose and decreasing the angle of the cellulose microfibrils are common ways to make materials stronger. Table 3 compares the engineering qualities of natural and synthetic fibers. Figure 5 is a schematic showing the structure of natural fibers.

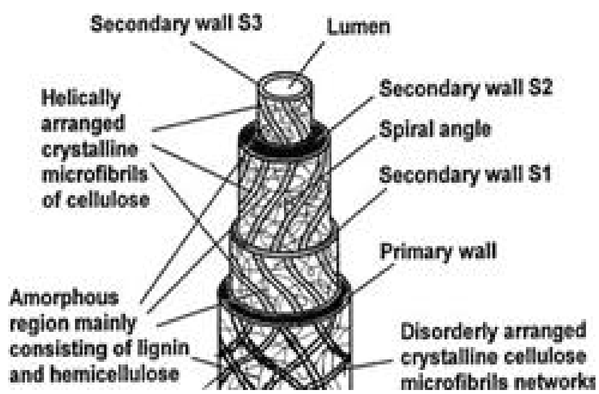

Figure 5. Structure of Natural Fibers.

Raw natural fiber has various drawbacks that make it incompatible with polymers, including a high moisture percentage, dead cells, wax, and oil. The solution is to modify their outer layer. The primary goal of surface functionalization is to increase composite systems' durability by improving natural fiber's qualities. Chemical, enzymatic, corona, plasma, and coupling agent treatments are all viable options for modifying surfaces. These treatments focus on the amorphous part of cellulose to enhance the contact between the fibers and the matrix. The amorphous part of cellulose has a high concentration of hydroxyl groups, giving the fiber a polar character and reducing its ability to interact with the matrix. So, surface morphology was used to reduce or eliminate hydrogen bonds, which improved adhesion to the matrix and the mechanical characteristics of the fiber. Plants used to make natural fibers fall into main and

Table 4. Types of hybrid natural fiber/synthetic fiber reinforced polymer matrix used in the ballistic application[25]

Hybrid Natural Fiber/ Synthetic Fiber	Polymer Matrix	Remarks
Carbon Aramid	Epoxy	Using different layers for each sample
Woven Kenaf & Kevlar	Epoxy	Using Amine Hardener
E-Glass Fiber	Epoxy	A single fiber diameter of 14e16 mm was used. E-glass fiberswere sized using epoxy silanes of max. 0.4% by weight
Kevlar	Thermosetting Resin	Avg. fiber weight fraction of 75% for each sample
Woven Fabric	Unsaturated Polyester Resin	Using 50% Fiber Volume
Aramid & Kevlar	Epoxy	Using plain Kevlar

secondary categories (Figure 6)[24]. Cotton, jute, kapok, hemp, kenaf, and sisal are all examples of "primary plants," whereas "secondary plants" include bananas, coconut coir, pineapples, and oil palms. Every year, over 30 metric tonnes of natural fibers are generated and used as raw materials or by-products in countless industries, such as clothes, packaging, paper, cars, buildings, and sports goods. Materials manufactured from animal fibers instead of plant fibers might include wool, silk, feathers, feathery fiber, and animal hair. Natural fibers have been utilized for centuries in many developing nations. When cellulose levels are low, higher interfacial adhesion occurs between components due to the poor interaction between the fiber and the adjacent moisture content. Asa result, it is better suited for heavier ballistic applications in general. Table 4 details the variety of polymercomposites that may be used for ballistic applications and whether they are reinforced with natural or synthetic components[25].

Despite competition from natural fibers throughout the years, the market for synthetic fibers must grow. There has been a resurgence of interest in using natural additives, especially in the automobile sector. Natural additives are being used to replace glass fiber. Natural fiber has essentially supplanted synthetic fiber in high-performance materials, such as those used in the automobile and aerospace sectors. To promote the use of natural textiles, the German car industry plans to produce bio-renewable components. Due to their environmental and economic benefits over synthetic reinforcing materials, natural fibers have attracted the attention of academics and engineers. When used in composites, natural fibers improve degradability and reduce pollution[26]. They are preferred since their usage has a less negative effect on the environment and people's health. Producing natural fibers requires around 17 percent of the energy to manufacture artificial fibers like glass fiber[27]. NPP composites natural fiber-reinforced polypropylene composites and NPP composites with metal plates as the approaching and backing material have been evaluated in previous studies in terms of their ballistic characteristics. The

Figure 6. Various Types of Natural Fibers[25].

study examined the functionality of natural fibres such flax, hemp, and jute[28]. By using compression molding, we were able to create composites with a fiber volume fraction of 46%. A sufficient amount of study was also done to understand the failure mechanisms caused by hybridization[29]. It demonstrated that shearing, delamination, and fiber breakage were all more likely to occur at the point of contact[30,31]. For their study, Monteiro et al. investigated the ability of a singular herbal fiber derived from the fique shrub to be used in plastic composite-sponsored MBAS. Researchers discovered that polyester resin's thermal and viscoelastic characteristics improved when mixed with fiberglass fibers[32,33]. The sand mold depression was 15 mm deep for the polyester/Kevlar composite and 23 mm deep for the fiberglass/polyester composite.

The cost of a polyester/fiberglass composite MBAS would be 13 times less than an MBAS made of a composite of polyester and kevlar, according to industry experts' price estimations. The ballistic impact parameters of composites reinforced with 2D/3D Kevlar and basalt fibre on a polypropylene basis were examined in the hybrid composite research[34]. The symmetric and asymmetric stacking processes make the two types of composites. A hybrid was created when basalt and Kevlar threads were used to weave fabric. A 9 mm full metal jacket bullet, comprised of a lead core and a brass jacket, was used in ballistic impact testing at velocities ranging from 365 to 435 meters per second. There was a barrage of gunfire on both laminates. The non-symmetric laminate had basalt fabric on one side and 3-Dimensional Kevlar fabric on the other[35].

4.0 Conclusion and Future Scope

1. Nanocellulose offers military potential for exceptional mechanical properties. Future research should focus on optimizing functionalization and exploring new surface modification techniques for specific applications.
2. Nanocellulose integration in military packaging enhances defense, durability, and environmental acceptability, revolutionizing equipment protection and transportation. Further research should explore scalability and real-world performance, while standardized testing methods validate their effectiveness in practical military scenarios.
3. Nanocellulose's potential in electrochemical energy storage devices offers lightweight, adaptable solutions for military applications. Further investigation into conductive functionalization and interdisciplinary collaboration between material scientists and energy experts is needed.
4. Nanocellulose's fire retardant properties make it valuable for improving fire safety in military equipment and structures. Research should enhance flame retardant properties, conduct comprehensive fire testing, and develop standards for fire-resistant materials.
5. Nanocellulose's potential in military medical settings, including bioengineering and tissue repair, is promising for improving healthcare outcomes. Future research should explore its compatibility with medical technologies and its potential for military-specific wound healing and drug delivery methods.

5.0 Declaration of Interest

The authors declare that they have no known competing financial interests or any personal relationships which could influence the contents/work of this research paper.

6.0 References

1. Norrrahim MNF, Mohd Nor Faiz, Kasim NAM, Knight VF, Ujang FA, Janudin N, Abdul Razak MAI, Ahmad Shah NA, et al. Nanocellulose: The next super versatile material for the military. Materials Advance. 2021; 2(5):1485-1506.
2. Patil NA, Pedapati SR, Mamat OB, Hidayat Syah Lubis AM. Optimization of friction stir process parameters for enhancement in surface properties of Al 7075-SiC/Gr hybrid surface composites. Coatings. 2019; 9(12):830.
3. Nurazzi NMF, Asyraf MRM, Khalina A, Abdullah N, Aisyah HA, Rafiqah SA, Sabaruddin FA, *et al.* A review on natural fiber reinforced polymer composite for bulletproof and ballistic applications. Polymers. 2021; 13(4):646.
4. Trache D, Tarchoun AF, Derradji M, Hamidon TS, Masruchin N, Brosse N, Hussin MH. Nanocellulose:

From fundamentals to advanced applications. Frontiers in Chemistry. 2020; 8:392.

5. Congressional Research Service. Government Expenditures on Defense Research and Development by the United States and Other OECD Countries: Fact Sheet. 2020.
6. Dutta S, Kim J, Ide Y, Kim JH, Hossain MS, Bando Y, Yamauchi Y, Wu KC. 3D network of cellulose-based energy storage devices and related emerging applications. Materials Horizons. 2017; 4(4):522-45.
7. Norrrahim MN, Ariffin H, Yasim-Anuar TA, Hassan MA, Nishida H, Tsukegi T. One-pot nanofibrillation of cellulose and nanocomposite production in a twinscrew extruder. In: IOP Conference Series: Materials Science and Engineering. 2018 Jun 1; 368:012034
8. Duong HM, Nguyen ST. Nanocellulose aerogels as thermal insulation materials. Nano and Biotech Based Materials for Energy Building Efficiency. 2016; 411-27.
9. Lin N, Huang J, Dufresne A. Preparation, properties and applications of polysaccharide nanocrystals in advanced functional nanomaterials: a review. Nanoscale. 2012; 4(11):3274-94.
10. Rusli R, Eichhorn SJ. Determination of the stiffness of cellulose nanowhiskers and the fiber-matrix interface in a nanocomposite using Raman spectroscopy. Applied Physics Letters. 2008 Jul 21; 93(3).
11. Mahfoudhi N, Boufi S. Nanocellulose as a novel nanostructured adsorbent for environmental remediation: a review. Cellulose. 2017 Mar; 24:1171- 97.
12. Rusli R, Eichhorn SJ. Determination of the stiffness of cellulose nanowhiskers and the fiber-matrix interface in a nanocomposite using Raman spectroscopy. Applied Physics Letters. 2008 Jul 21; 93(3).
13. Etuk VE, Oboh IO, Etuk BR, Johnson EO, Egemba K. Nanocellulose: Types, Sythesis and Applications. In: European conference on sustainability, energy & the environment 2018 official conference proceedings. p. 2018.
14. Rebelo R, Fernandes M, Fangueiro R. Biopolymers in medical implants: a brief review. Procedia Engineering. 2017 Jan 1; 200:236-43.
15. Patel DK, Dutta SD, Lim KT. Nanocellulose-based polymer hybrids and their emerging applications in biomedical engineering and water purification. RSC Advances. 2019; 9(33):19143-62.
16. Wang, Xiaoju, Qingbo Wang, and Chunlin Xu. 2020. Nanocellulose-Based Inks for 3D Bioprinting: Key Aspects in Research Development and Challenging Perspectives in ApplicationsA Mini Review. Bioengineering. 7(2):40. https://doi.org/10.3390/bioengineering7020040
17. Lin N, Dufresne A. Nanocellulose in biomedicine: Current status and future prospect. European Polymer Journal. 2014 Oct 1; 59:302-25.
18. Cherian BM, Leão AL, de Souza SF, de Olyveira GM, Costa LM, Brandão CV, Narine SS. Bacterial nanocellulose for medical implants. Advances in Natural Polymers: Composites and Nanocomposites. 2013; 337-59.
19. Farid M, Purniawan A, Susanti D, Priyono S, Ardhyananta H, Rahmasita ME. Nanocellulose based polymer composite for acoustical materials. AIP Conference Proceedings. 2018 Apr 3; 1945(1).
20. Mahfoudhi N, Boufi S. Cellulose-Reinforced Nanofiber Composites. Elsevier Ltd. 2017; 277–304.
21. Megashah LN, Ariffin H, Zakaria MR, Hassan MA, Andou Y, Padzil FNM. Cellulose. 2020; 27:7417–7429.
22. Norrrahim MNF, Ariffin H, Yasim-Anuar TAT, Ghaemi F, Hassan MA, Ibrahim NA, *et al*.
23. Ngee H, Yunus WMZW. Cellulose. 2018; 25:3853–3859.
24. Available from: https://www.sipri.org/media/press-release/2020/global-military-expenditure-sees-largest-annual-increase-decade-says-sipri-reaching-1917-billion. [Accessed 22-Oct-2020].
25. Asim M, Abdan K, Jawaid M, Nasir M, Dashtizadeh Z, Ishak MR, Hoque ME, Deng Y. Are view on pineapple leaves fiber and its composites. Int J Polym Sci. 2015.
26. National Research Council. Materials Research to Meet 21st Century Defense Needs. National Academies Press. 2003.
27. Ahmad Ilyas R, *et al*. Sugar palm (*Arenga pinnata* (Wurmb.) Merr) cellulosic fiber hierarchy: a comprehensive approach from macro to the nanoscale. J Mater Res Technol. 2019; 8(3):2753–2766.
28. Malainine ME, Mahrouz M, Dufresne A. Thermoplastic nanocomposites based on cellulose microfibrils from *Opuntia ficus-indica* parenchyma cell. Compos Sci Technol. 2005; 65(10):1520–1526.
29. Lau Kt, Hung PY, Zhu MH, Hui D. Properties of natural fiber composites for structural engineering applications. Compos Part B Eng. 2018; 136:222–233.
30. Radif ZS, Alil A, Abdan K. Development of a green combat armor from rame- kevlar- polyester composite. Pertanika J Sci Technol. 2011; 19:339–348.
31. George M, Mussone PG, Alemaskin K, Chae M, Wolodko J, Bressler DC. Enzymatically treated natural fibers as reinforcing agents for biocomposite material: Mechanical, thermal, and moisture absorption characterization. J Mater Sci. 2016; 51:2677–2686.

32. Nurazzi MN, Khalina A, Sapuan SM, Dayang Laila AM, Rahmah M. Curing behavior of unsaturated polyester resin and interfacial shear stress of sugar palm fiber. J Mech Eng Sci. 2017; 11:2650–2664.
33. Asyraf MRM, Rafidah M, Azrina A, Razman MR. Dynamic mechanical behavior of kenaf cellulosic fiber biocomposites: A comprehensive review on chemical treatments. Cellulose. 2021.
34. Patil NA, Pedapati SR, Marode RV. Wear analysis of friction stir processed AA7075-SiC-graphite hybrid surface composites. Lubricants. 2022; 10(10):267.
35. Patil NA, Pedapati SR, Mamat OB, Hidayat Syah Lubis AM. Effect of SiC/fly ash reinforcement on surface properties of aluminum 7075 hybrid composites. Coatings. 2020; 10(6):541.