Seshat's 100% Organic Hemp Bionanocomposites: A Theoretical Proposal for a Fully Hemp-Derived Nanocomposite Material (Diamond Composites)

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Abstract

This paper presents a theoretical proposal for *Seshat's 100% Organic Hemp Bionanocomposites* (referred to as *Diamond Composites* for marketing purposes) – a novel class of nanocomposite materials produced entirely from hemp. The proposed material integrates hemp-derived carbon nanosheets (HDCNS), sometimes referred to as "hemp graphene" (as used by Dr. David Mitlin), into an organic epoxy matrix synthesized exclusively from hemp oil and hemp lignin. By leveraging hemp's rapid growth, carbon-negative properties, and soil-regenerative benefits, this concept outlines an eco-friendly composite with promising mechanical and thermal characteristics. It is important to note that all results and formulations presented here are entirely theoretical; no prototypes have yet been fabricated. AI tools were used to assist in structuring the research and drafting this document.

Keywords: Hemp nanocomposites, HDCNS, hemp graphene, organic epoxy, hemp oil, hemp lignin, Diamond Composites, theoretical materials, sustainable innovation.

1 Introduction

Advances in biomass-based nanomaterials have shown that hemp can serve as an abundant and sustainable source of advanced carbon nanostructures, such as hemp-derived carbon nanosheets (HDCNS) (also known informally as *hemp graphene*) [1]. While the term "hemp graphene" has been used to describe these materials, it is important to note that HDCNS differ structurally from pure graphene, exhibiting a more amorphous structure and the presence of heteroatoms. Whereas most previous studies rely on synthetic or petrochemical matrices, the approach described here employs a fully organic method. By formulating an epoxy resin exclusively from hemp oil [2] and hemp lignin [3], and dispersing HDCNS into this matrix, the concept of *100% Organic Hemp Bionanocomposites* (referred to as *Diamond Composites* for marketing purposes) is born. We introduce the name "Diamond Composites" as a descriptive marketing term intended to capture the potential high-performance characteristics of these hemp bionanocomposites.

The theoretical framework for these bionanocomposites is underpinned by several key benefits:

- **Sustainability:** Hemp is a fast-growing, carbon-negative crop that contributes to soil regeneration.
- **100% Organic Composition:** Both the matrix (hemp oil and lignin) and the nanofiller (HDCNS) are derived entirely from hemp.
- **Versatility:** The concept permits the inclusion of additional hemp-based additives (e.g., hemp fiber, hemp hurd) and recycled materials to further enhance mechanical performance and promote environmental remediation.

This proposal outlines the synthesis routes, processing techniques, and potential applications of these *Diamond Composites* across a range of fields—from electronics and energy storage to aerospace to sustainable construction.

2 Theoretical Framework and Proposed Methodology

2.1 Components and Composition

The proposed composite consists of three primary hemp-derived components:

1. **Hemp Oil (HO):** Serves as the reactive binder after epoxidation [2].
2. **Hemp Lignin (HL):** Acts as a natural curing agent that enhances strength and thermal stability [3].
3. **Hemp-Derived Carbon Nanosheets (HDCNS):** Provide reinforcement and improved thermal conductivity.

Optional additives (e.g., hemp fibers, hemp hurd, and recycled particulates) are theoretically introduced to tailor the material properties for specific applications. We will assume a composition of 60

2.2 Synthesis of the Hemp Epoxy Matrix

The organic epoxy matrix is proposed to be prepared by a two-step process:

1. *Epoxidation of Hemp Oil:* Hemp oil is reacted with a peracid (e.g., peracetic acid) at 60-70°C for 4-6 hours to convert unsaturated bonds into oxirane rings. The epoxidation process can be carried out with acetic acid (99.7
2. *Crosslinking with Hemp Lignin:* The epoxidized oil is blended with purified hemp lignin and a bio-based hardener (e.g., citric acid) under controlled conditions (e.g., 120°C for 2 hours) to form a thermosetting resin. The blending will be achieved using a high-shear mixer to ensure homogeneity. The specific ratio of epoxidized hemp oil to hemp lignin will influence the crosslink density and thus the final material properties. A lignin content of 20

2.3 Production of HDCNS

HDCNS are proposed to be generated from hemp bast fibers using a two-step process:

1. *Hydrothermal Carbonization:* Hemp bast fibers are treated in an autoclave at approximately 180°C for 24 hours to produce a carbon-rich precursor. The residence time and temperature during hydrothermal carbonization significantly affect the yield and structure of the carbon material [12]. Optimizing these parameters can maximize the carbon content and minimize energy consumption.
2. *Chemical Activation:* The precursor is chemically activated (e.g., with potassium hydroxide at a KOH:carbon ratio of 4:1) at elevated temperatures (e.g., 800°C under an inert atmosphere) to yield nanosheets with thicknesses in the range of 10–30 nm. The activation temperature and the type of activating agent influence the surface area and pore size distribution of the HDCNS [13]. Lower activation temperatures (e.g., 700°C) may reduce energy consumption while still achieving a high surface area.

2.4 Composite Fabrication

The composite is formed by homogeneously dispersing HDCNS into the hemp epoxy matrix. To achieve uniform dispersion, the HDCNS will first be sonicated in a suitable solvent (e.g., ethanol) for 30-60 minutes at a power of 100-200 W. A surfactant (e.g., lecithin at a concentration of 1-2 wt

3 Properties of Hemp-Derived Components

3.1 Hemp Oil (HO)

Hemp oil is extracted from the seeds of the *Cannabis sativa* plant and is renowned for its rich composition of unsaturated triglycerides. The primary properties of hemp oil include:

- **Chemical Composition:** High in polyunsaturated fatty acids (PUFA) (70-90
- **Viscosity:** Exhibits a relatively low viscosity, making it suitable as a base for bio-based resins and polymers. Typical viscosity ranges from 30-50 cP at room temperature.
- **Reactivity:** The presence of multiple double bonds allows for chemical modifications, such as epoxidation, facilitating its use in producing thermosetting resins.
- **Biodegradability:** Being a natural product, hemp oil is biodegradable and environmentally friendly.

3.2 Hemp Lignin (HL)

Lignin is a complex aromatic polymer found in the cell walls of plants, providing rigidity and resistance to microbial attacks. Hemp lignin possesses unique properties:

- **Chemical Structure:** Composed of phenolic compounds, contributing to its antioxidant properties. The exact composition depends on the extraction method and plant source, with variations in the proportions of guaiacyl (G), syringyl (S), and p-hydroxyphenyl (H) units.
- **Thermal Stability:** High thermal stability, with decomposition temperatures typically above 200°C [11], which can enhance the thermal properties of composites. The thermal stability is influenced by the type of lignin and the heating rate.
- **Electrical Properties:** Can exhibit electrical conductivity [5], making it a potential candidate for applications requiring antistatic or conductive materials, though further research is needed to quantify this in hemp lignin specifically. Reported conductivity values vary widely depending on the lignin source and measurement method. Chemical modification of lignin (e.g., doping) can significantly enhance its electrical conductivity.
- **Compatibility:** The aromatic structure of lignin allows for good compatibility with other aromatic polymers, aiding in the development of cohesive composite materials. Pre-treatment of lignin (e.g., esterification) can improve its compatibility with hydrophobic polymers.

3.3 Hemp-Derived Carbon Nanosheets (HDCNS)

HDCNS, sometimes referred to as ”hemp graphene” (as used by Dr. David Mitlin), are carbon nanosheets derived from hemp fibers through processes like hydrothermal carbonization and chemical activation. They consist of interconnected two-dimensional nanosheets with thicknesses ranging from 1 to 30 nm. While exhibiting graphene-like properties such as high surface area and electrical conductivity, HDCNS differ structurally from pure graphene due to their more amorphous nature and the presence of oxygen and nitrogen functionalities on their surfaces. Their notable properties include:

- **Morphology:** Consist of interconnected two-dimensional nanosheets with thicknesses ranging from 10 to 30 nm, resembling the structure of graphene [1, 6]. The specific morphology is influenced by the HTC and activation conditions, with variations in the number of layers and the degree of graphitization.
- **Surface Area:** High specific surface area, beneficial for applications in energy storage and catalysis. Can have surface area up to 2287 m2/g [1, 6]. The surface area is influenced by the activation temperature and the type of activating agent.
- **Electrical Conductivity:** Demonstrates good electrical conductivity, ranging from 211-226 S/m [1, 6], making them suitable for use in supercapacitors and conductive composites. The conductivity is lower than pristine graphene due to defects and functional groups. Post-treatment (e.g., annealing) can improve the electrical conductivity.
- **Mechanical Strength:** High mechanical strength and stiffness, contributing to the reinforcement of composite materials. However, directly measuring the tensile strength of HDCNS is challenging.
- **Thermal Conductivity:** Possess good thermal conductivity, advantageous for heat dissipation applications. The thermal conductivity is expected to be lower than pristine graphene due to defects and amorphous regions. Isotropic thermal conductivity can be assumed.

This detailed overview of the properties of hemp oil, hemp lignin, and hemp-derived carbon nanosheets underscores their potential in creating sustainable, high-performance bionanocomposite materials.

4 Synergistic Interaction of Hemp-Derived Components

The integration of hemp oil, hemp lignin, and hemp-derived carbon nanosheets (HDCNS) into a composite material leverages the unique properties of each component, resulting in a material with enhanced mechanical, thermal, and electrical characteristics.

4.1 Role of Epoxidized Hemp Oil (EHO) as the Matrix

Epoxidized hemp oil serves as the polymer matrix, providing the foundational structure of the composite. Its notable attributes include:

- **Flexibility and Toughness:** The long-chain fatty acids in hemp oil contribute to the flexibility and toughness of the cured resin, which can enhance the composite's impact resistance. The degree of unsaturation in the hemp oil affects the flexibility of the resulting epoxy.
- **Chemical Reactivity:** The epoxidation process introduces reactive oxirane rings, enabling crosslinking during curing to form a robust three-dimensional network [2]. The degree of epoxidation affects the crosslink density and mechanical properties. The choice of curing agent influences the final properties of the epoxy.

4.2 Function of Hemp Lignin as a Natural Filler and Compatibilizer

Incorporating hemp lignin into the composite serves multiple purposes:

- **Mechanical Enhancement:** Lignin's rigid aromatic structure can improve the tensile strength and stiffness of the composite [8]. The extent of improvement depends on the lignin content and dispersion. Proper dispersion is essential to prevent agglomeration and maintain mechanical integrity.
- **Thermal Stability:** The high thermal stability of lignin contributes to the composite's ability to withstand elevated temperatures.
- **Electrical Properties:** Lignin's inherent electrical characteristics may impart antistatic properties to the composite [5], pending further investigation of hemp-specific lignin. The electrical properties are sensitive to moisture content. Chemical modification can be used to enhance the electrical conductivity of lignin.
- **Compatibility Improvement:** Lignin can act as a compatibilizer, enhancing the interfacial adhesion between the hydrophobic matrix and hydrophilic fillers [9]. Pre-treatment of lignin (e.g., esterification) can improve its compatibility with the matrix and HDCNS.

4.3 Contribution of Hemp-Derived Carbon Nanosheets (HDCNS)

The addition of HDCNS provides significant benefits:

- **Electrical Conductivity:** HDCNS exhibit good electrical conductivity [1], which can enhance the composite's potential for applications requiring electrical conduction. The overall conductivity depends on the HDCNS loading and dispersion. Achieving a percolating network of HDCNS is crucial for maximizing conductivity.
- **Mechanical Reinforcement:** The high aspect ratio and strength of HDCNS contribute to the overall mechanical robustness of the composite. The effectiveness of reinforcement depends on the interfacial bonding between the HDCNS and the matrix. Surface functionalization of HDCNS can improve their interfacial adhesion.
- **Thermal Conductivity:** HDCNS can improve the thermal conductivity of the composite, aiding in heat dissipation for high-performance applications. The improvement depends on the HDCNS loading and alignment. Alignment of HDCNS can be achieved through techniques like magnetic field alignment or shear alignment.

4.4 Synergistic Effects in the Composite

The combined use of these hemp-derived components results in a composite material where:

- The flexible EHO matrix accommodates the rigid lignin and HDCNS fillers, leading to a balanced combination of toughness and strength.
- Lignin enhances the interfacial bonding between the matrix and fillers, ensuring efficient stress transfer and improved mechanical performance.
- HDCNS provide pathways for electrical and thermal conductivity, expanding the composite's functional applications.

This holistic integration of hemp-derived materials exemplifies a sustainable approach to developing high-performance bionanocomposites with tailored properties for diverse applications.

5 Theoretical Property Estimation

Based on the assumed composition of 60

- **Assumptions:** We assume the following properties for the individual components (these values are based on literature and estimations):
  - Epoxidized Hemp Oil: Density = 0.95 g/cm^3 (estimated), Tensile Strength = 40 MPa [2], Young's Modulus = 2 GPa (estimated, based on similar bio-epoxies), Thermal Conductivity = 0.2 W/mK (estimated, similar to other epoxies)
  - Hemp Lignin: Density = 1.3 g/cm^3 (typical lignin density), Tensile Strength = 60 MPa (based on various lignin composites [8]), Young's Modulus = 5 GPa (estimated), Thermal Conductivity = 0.3 W/mK (estimated)
  - HDCNS: Density = 1.8 g/cm^3 [1], Tensile Strength = 150 MPa (estimated, accounting for defects and functional groups), Young's Modulus = 15 GPa (estimated, accounting for defects and functional groups), Thermal Conductivity = 100 W/mK (conservative estimate based on [1], accounting for defects and lower crystallinity)
- **Calculations:** Using the rule of mixtures:
  - Density: $\rho_c = 0.6\rho_{HO} + 0.2\rho_{HL} + 0.2\rho_{HDCNS} = 0.6(0.95) + 0.2(1.3) + 0.2(1.8) = 1.19$ g/cm^3
  - Tensile Strength: $TS_c = 0.6TS_{HO} + 0.2TS_{HL} + 0.2TS_{HDCNS} = 0.6(40) + 0.2(60) + 0.2(150) = 66$ MPa
  - Young's Modulus: $E_c = 0.6E_{HO} + 0.2E_{HL} + 0.2E_{HDCNS} = 0.6(2) + 0.2(5) + 0.2(15) = 5.2$ GPa
  - Thermal Conductivity: $k_c = 0.6k_{HO} + 0.2k_{HL} + 0.2k_{HDCNS} = 0.6(0.2) + 0.2(0.3) + 0.2(100) = 20.18$ W/mK

Property	Estimated Value
Density (g/cm^3)	1.19
Tensile Strength (MPa)	66
Young's Modulus (GPa)	5.2
Thermal Conductivity (W/mK)	20.18

Table 1: Theoretical Property Estimation for 100% Organic Hemp Bionanocomposite

Note: These are rough estimates. More sophisticated models (e.g., Halpin-Tsai, Mori-Tanaka) could be used for a more accurate prediction, especially for mechanical properties. The thermal conductivity estimate is also very sensitive to the dispersion of the HDCNS. Given the presence of defects in the HDCNS and potential interfacial issues, the tensile strength, Young's Modulus and thermal conductivity have been conservatively estimated. The rule of mixtures assumes perfect dispersion and interfacial bonding, which is unlikely to be achieved in practice.

6 Potential Applications

Given its anticipated combination of good mechanical strength, thermal stability, environmental benefits, and potential for tailored electrical conductivity, the theoretical *Diamond Composites* could be applied in a wide range of sectors.

6.1 Industrial Applications

- **Automotive:** Lightweight structural components (e.g., body panels, interior parts) to improve fuel efficiency and reduce emissions.
- **Aerospace:** Aircraft interior components, drone structures, and potentially even primary structural elements in future aircraft designs, contributing to weight reduction and improved performance.
- **Construction:** Sustainable building materials, including insulation panels, structural supports, and roofing materials. The biodegradability of the composite could be advantageous for temporary structures or deconstruction.
- **Marine:** Boat hulls, decks, and other marine components. The water resistance and biodegradability (in certain formulations) of the composite would be valuable in marine environments.
- **Packaging:**** Biodegradable packaging materials for food and other products, reducing reliance on petroleum-based plastics.
- **Sporting Goods:**** Lightweight and durable components for sports equipment, such as bicycle frames, skis, and surfboards.
- **Wind Energy:**** Blades for wind turbines, offering a more sustainable alternative to traditional fiberglass composites.

6.2 Commercial Applications

- **Electronics:**** Substrates for flexible electronics, printed circuit boards, and conductive coatings.
- **Energy Storage:**** Components for batteries and supercapacitors, leveraging the potential electrical conductivity of the HDCNS.
- **Consumer Goods:**** Cases for electronic devices, furniture components, and other consumer products, offering a sustainable and aesthetically pleasing alternative to traditional materials.
- **Textiles:**** Reinforcement for textiles, creating stronger and more durable fabrics with tailored properties.
- **Medical:**** Biocompatible implants, drug delivery systems, and medical devices.

6.3 Military Applications (Theoretical)

- **Lightweight Armor:** Body armor plates, vehicle armor, and structural reinforcement for military vehicles, reducing weight and improving mobility.
- **Stealth Technology:**** Coatings and structural components with tailored electromagnetic properties for stealth applications. The HDCNS could be used to create radar-absorbing materials (RAM).
- **Unmanned Systems:**** Structures for unmanned aerial vehicles (UAVs), unmanned ground vehicles (UGVs), and other unmanned systems, improving performance and reducing weight.
- **Field Shelters:**** Lightweight and rapidly deployable field shelters for military personnel. The biodegradability of the composite could be advantageous for temporary bases.

- **Protective Gear:**** Helmets, visors, and other protective gear for soldiers and law enforcement officers.
- **Ammunition Components:**** Biodegradable ammunition components for training exercises, reducing environmental impact.

It is important to emphasize that these applications are highly theoretical and depend on achieving the desired material properties, addressing the identified challenges, and meeting the specific performance requirements for each application. Further research and development are essential to validate the potential of *Diamond Composites* in these various sectors.

7 Cost Analysis (Theoretical)

A detailed cost analysis is crucial for evaluating the economic viability of *Diamond Composites*. This analysis is based on available data and estimations and should be refined with more specific information.

- **Hemp Cultivation:**** The cost of hemp cultivation varies significantly. Based on a review of hemp cultivation costs [16], a conservative estimate is $500 per acre.
- **Hemp Oil Extraction:**** Cold pressing is a relatively simple and cost-effective method, with an estimated cost of $0.20 per lb of hemp seed. Assuming a seed yield of 500 lbs per acre and an oil extraction rate of 30
- **Hemp Lignin Extraction:**** Lignin extraction from hemp hurds can be integrated with other hemp processing operations, reducing costs. Assuming a cost of $0.10 per lb of hemp hurds and a lignin extraction rate of 20
- **HDCNS Synthesis:**** Hydrothermal carbonization and chemical activation are energy-intensive processes. A conservative estimate is $5 per lb of HDCNS, based on the cost of chemicals, energy, and labor.
- **Composite Fabrication:**** The cost of composite fabrication depends on the processing method and production volume. Assuming a molding process and a production volume of 1000 lbs, the fabrication cost is estimated to be $1 per lb.

Material Cost per lb of Composite:** Based on the assumed composition (60

- EHO: 0.6 lb * $1.33/lb = $0.80
- HL: 0.2 lb * $0.50/lb = $0.10
- HDCNS: 0.2 lb * $5/lb = $1.00
- Fabrication: $1.00
- **Total: $2.90 per lb of Composite**

Comparison to Alternatives:** The estimated cost of $2.90 per lb is competitive with some traditional composites like fiberglass. However, carbon fiber composites are typically more expensive. The environmental benefits of *Diamond Composites* may justify a premium price in some applications.

Future Cost Reductions:** The cost of *Diamond Composites* can be reduced through:

- **Scale-up of Production:**** Increasing the production volume will reduce the per-unit cost due to economies of scale.
- **Optimization of Synthesis and Processing:**** Optimizing the HTC, activation, and composite fabrication processes will reduce energy consumption and material waste.
- **Development of More Efficient Extraction Methods:**** Developing more efficient and environmentally friendly methods for extracting hemp oil and lignin will reduce costs.
- **Use of Waste Streams:**** Utilizing waste streams from hemp processing (e.g., hemp hurds) as feedstock for HDCNS synthesis will further reduce costs and improve the environmental sustainability of the process.

Note:** This is a highly simplified cost analysis. A detailed cost model, incorporating all these factors and specific to the intended location and scale of production, is necessary to accurately assess the economic viability of *Diamond Composites*.

8 Challenges and Limitations

This theoretical study has several limitations that should be considered. The property estimations are based on simplified models and assumed material properties. Achieving uniform dispersion of HDCNS in the hemp epoxy matrix may be challenging due to the high surface area and potential for agglomeration. The long-term durability and environmental stability of the hemp-derived materials are unknown and require further investigation. Batch-to-batch variability in the properties of hemp oil and lignin could affect the reproducibility of the composite's properties.

Specific challenges include:

- **HDCNS Dispersion:**** Achieving uniform dispersion of HDCNS in the viscous hemp epoxy matrix requires careful control of the sonication parameters, surfactant selection, and mixing process. Agglomeration of HDCNS can lead to reduced mechanical properties and electrical conductivity. Potential solutions include:
  - Optimizing the sonication parameters (time, power, frequency) to break up HDCNS agglomerates without damaging the nanosheets.
  - Using a combination of surfactants with different polarities to stabilize the HDCNS dispersion.
  - Employing a three-roll mill to further improve HDCNS dispersion after sonication.
- **Interfacial Bonding:**** The interfacial bonding between the HDCNS and the hemp epoxy matrix is crucial for effective stress transfer. Surface modification of HDCNS may be necessary to improve their adhesion to the matrix. Potential solutions include:
  - Functionalizing the HDCNS surface with epoxy groups or other reactive groups to promote covalent bonding with the matrix.
  - Coating the HDCNS with a thin layer of polymer to improve their compatibility with the matrix.
  - Using a coupling agent to bridge the gap between the HDCNS and the matrix.
- **Moisture Sensitivity:**** Hemp-derived materials are generally more sensitive to moisture than traditional polymers. The moisture content can affect the mechanical properties, electrical conductivity, and dimensional stability of the composite. Potential solutions include:

- Incorporating a hydrophobic additive into the composite to reduce moisture absorption.
- Coating the composite with a moisture-resistant sealant.
- Storing the composite in a dry environment.

- **Thermal Stability:**** While lignin offers good thermal stability, the long-term thermal stability of the composite needs to be assessed, especially for high-temperature applications. Potential solutions include:
  - Incorporating a thermal stabilizer into the composite.
  - Crosslinking the hemp epoxy matrix to improve its thermal stability.
  - Using a higher-grade hemp lignin with improved thermal stability.

- **Reproducibility:**** Batch-to-batch variability in the properties of hemp oil and lignin can affect the reproducibility of the composite's properties. Implementing rigorous quality control measures is essential. Potential solutions include:
  - Sourcing hemp oil and lignin from reputable suppliers with consistent quality control standards.
  - Characterizing the properties of each batch of hemp oil and lignin before using them in the composite.
  - Adjusting the composite formulation to compensate for variations in the properties of the hemp-derived materials.

Further research is needed to address these challenges and validate the theoretical predictions. Experimental studies are necessary to characterize the properties of the hemp-derived materials, optimize the synthesis and processing methods, and assess the long-term performance of the composite.

9 Conclusion

This theoretical proposal introduces *Seshat's 100% Organic Hemp Bionanocomposites* (referred to as *Diamond Composites* for marketing purposes)—a fully hemp-derived, eco-friendly nanocomposite material. By integrating hemp-derived carbon nanosheets (HDCNS) with an epoxy matrix formulated exclusively from hemp oil and hemp lignin, a new subclass of composites is proposed that combines sustainability with good performance. It is important to stress that all aspects of this research are theoretical; no prototypes or experimental samples have been fabricated at this stage. AI tools were used to assist in structuring and drafting this document. This work is released openly under the Creative Commons Attribution 4.0 License to encourage further collaboration and innovation in sustainable materials research. The theoretical property estimations suggest promising mechanical and thermal properties, but further research is needed to validate these predictions and address potential challenges. A more detailed and location-specific cost analysis is also essential to assess the economic viability of *Diamond Composites*. The potential solutions outlined in the "Challenges and Limitations" section provide a roadmap for future research and development efforts. The wide range of potential industrial, commercial, and military applications highlights the versatility of this theoretical material.

Acknowledgments

I acknowledge the assistance of AI tools in structuring and drafting this theoretical proposal. I also refer the interested reader to my prior works on HDCNS-Composites [17].

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