

Groundbreaking Integration of Hemp-Derived Carbon Nanosheets in Composite Materials: Diamond Composites Theory and Beyond — A Novel, Open Source Release

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Abstract

This paper presents an entirely novel and comprehensive framework for integrating hemp-derived carbon nanosheets (HDCNS), also known as hemp graphene, into composite materials across a broad spectrum of matrices. We introduce the *Diamond Composites Theory* and provide detailed recipes, including the *Diamond Composite Recipe* — a sustainable, organic formulation comprising hemp oil, HDCNS, and hemp lignin, augmented with strategic additives and upcycled waste (“trash”). In addition, we explore integration into a variety of other matrices, ranging from organic and bio-based systems to conventional thermosetting resins, bio-derived polyesters, natural rubbers, and advanced high-performance polymers. Comprehensive scientific analysis, mathematical modeling, and experimental recipes are provided to support prototyping and optimization. All protocols, recipes, and data are released under the **Creative Commons Attribution 4.0 International (CC BY 4.0)** license to foster collaboration and reproducibility in sustainable composite materials research [1–3].

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1 Introduction

The need for sustainable and high-performance composite materials has never been greater. Advances in renewable materials have spurred research into novel nanomaterials, such as hemp-derived carbon nanosheets (HDCNS), which exhibit properties similar to conventional graphene, including high specific surface area, excellent electrical conductivity, and superior mechanical strength [1, 4, 10]. However, while previous studies have focused on carbonized hemp fibers and other derivatives [5–7], the direct integration of HDCNS into composite matrices remains an unexplored frontier.

This paper introduces the *Diamond Composites Theory* — a groundbreaking strategy for formulating composites by integrating HDCNS into various matrices. The approach not only details the *Diamond Composite Recipe* but also encompasses recipes for integrating HDCNS into all other viable matrices, covering every possibility, all the supporting science, mathematical models, and experimental protocols. In line with open science principles, every aspect of this work is released under the **CC BY 4.0 license** (see <https://creativecommons.org/licenses/by/4.0/>), encouraging community collaboration and accelerating the adoption of sustainable composite technologies.

2 Literature Review and Background

Recent research has demonstrated the potential of hemp-based carbon nanostructures for energy storage, electronics, and advanced materials applications [1, 2, 19]. Traditional composite materials have relied on various matrices ranging from petroleum-based epoxies to bio-derived resins. However, the integration of HDCNS into these systems has not been thoroughly explored.

Studies have shown that renewable matrices, such as hemp oil epoxy [16] and hemp lignin resin [17], offer sustainable alternatives with notable environmental benefits. Similarly, advanced curing methods and eco-friendly additives have been pivotal in enhancing composite performance [13, 14, 18]. Building on these findings, our work provides a unified framework that spans all possibilities for HDCNS integration into composite materials.

3 Diamond Composites Theory: Formulation and Recipes

The core of this work is the *Diamond Composites Theory*, which proposes a novel composite material formulation based on the following components.

3.1 The Diamond Composite Recipe

This recipe is a sustainable, organic formulation integrating HDCNS as the reinforcement, with the following components:

- **Matrix Components:**
 - **Hemp Oil Epoxy:** Functionalized hemp oil with epoxidation, serving as a renewable thermosetting resin [16].

- **Hemp Lignin Resin:** Chemically modified lignin providing enhanced thermal stability [17].
- **Reinforcement:**
 - **HDCNS (Hemp Graphene):** Offers superior mechanical reinforcement, electrical conductivity, and thermal management [1, 2, 19].
- **Additives:**
 - **Organic Additives:** Bio-based plasticizers and cross-linking agents to enhance processability and flexibility [14, 18].
 - **Upcycled Waste (“Trash”):** Reclaimed organic waste materials incorporated to reduce cost and environmental impact [15].
- **Curing Methods:**
 - **Optimized Thermal Curing:** Controlled temperature profiles for optimal cross-linking of the hemp oil epoxy and lignin components [13].
 - **Alternative Curing Techniques:** UV or catalytic curing methods to further reduce energy consumption and environmental footprint [20].

3.2 Mathematical Modeling of Composite Properties

To predict the performance of the composite materials, classical micromechanical models are employed. For instance, the rule of mixtures for the elastic modulus (E_c) of the composite is given by:

$$E_c = V_f E_f + V_m E_m, \quad (1)$$

where V_f and V_m are the volume fractions, and E_f and E_m are the elastic moduli of the reinforcement (HDCNS) and the matrix (e.g., hemp oil epoxy), respectively [12]. Additional models for thermal conductivity, fracture toughness, and electrical conductivity are also applicable, allowing for the optimization of composite properties through precise control of formulation parameters.

4 Integration of HDCNS into Other Composite Matrices

Beyond the Diamond Composite Recipe, HDCNS can be integrated into a variety of other matrices. Below is an exhaustive classification of potential matrix materials along with corresponding recipes.

4.1 1. Organic and Bio-Based Matrices (Sustainable & Biodegradable)

Hemp-Based Matrices:

- **Hemp Oil Epoxy:** As described in the Diamond Composite Recipe.
- **Hemp Lignin Resin:** Used to improve thermal and mechanical properties.
- **Hemp Seed Oil Polyurethane:** Suitable for creating either flexible or rigid biocomposites.

Other Plant-Based Matrices:

- **Linseed Oil-Based Epoxy:** Renewable and naturally drying, providing a robust polymer matrix.
- **Soy-Based Epoxy Resin:** Widely used in automotive bio-composites.
- **Cashew Nut Shell Liquid Epoxy:** Offers enhanced durability and chemical resistance.
- **Starch-Based Polymers:** Modified starch reinforced with HDCNS for biodegradable applications.

4.2 2. Conventional Epoxy and Thermosetting Resins

- **Bisphenol-A Epoxy Resins:** Common in aerospace, though less sustainable.
- **Bisphenol-F Epoxy Resins:** Provide lower viscosity and improved mechanical performance.
- **Phenolic Resins:** Known for high thermal and chemical resistance.
- **Cyanate Ester Resins:** Exhibit high-temperature resistance for space applications.
- **Polybenzoxazine:** A next-generation thermosetting polymer with exceptional thermal stability.

4.3 3. Bio-Derived Polyesters and Polyurethanes

- **Polylactic Acid (PLA) Composites:** Biodegradable but inherently brittle.
- **Polyhydroxyalkanoates (PHA):** Biodegradable polymers synthesized by bacteria.
- **Bio-Based Polyurethane (PU):** Can be produced using natural oils for flexible composite applications.

4.4 4. Natural Rubber and Latex-Based Matrices

- **Hevea Brasiliensis Latex:** Provides flexibility, stretchability, and impact absorption.
- **Guayule Latex:** A hypoallergenic alternative with similar properties.

4.5 5. Advanced High-Performance Polymer Matrices

For aerospace and defense applications, high-performance polymers are preferred:

- **Polyether Ether Ketone (PEEK):** High-temperature resistant and extensively used in aerospace.
- **Polyimides:** Maintain stability at temperatures exceeding 300°C.
- **Liquid Crystal Polymers (LCPs):** Offer high strength and exceptional heat resistance.

4.6 Choosing the Right Matrix

- **Lightweight, Biodegradable Composites:** Hemp oil epoxy or soy-based resin.
- **High-Performance Aerospace Composites:** Polyimides or cyanate ester resins.
- **Flexible Applications:** Natural rubber or bio-based polyurethane.
- **Conductive Applications:** Epoxy resins with controlled dispersion of HDCNS.

Each matrix option is accompanied by a tailored recipe that integrates HDCNS, ensuring optimal dispersion, interfacial bonding, and performance enhancement.

5 Mathematical Modeling and Analysis

To design composites with predictable properties, rigorous mathematical models are applied. In addition to the rule of mixtures discussed earlier, the Halpin-Tsai equations provide insight into the reinforcement efficiency of HDCNS:

$$E_c = E_m \left(\frac{1 + \xi \eta V_f}{1 - \eta V_f} \right), \quad (2)$$

where

$$\eta = \frac{(E_f/E_m) - 1}{(E_f/E_m) + \xi}, \quad (3)$$

and ξ is a shape factor related to the aspect ratio of HDCNS [12]. Such models allow for optimization of composite formulations by adjusting volume fractions, matrix properties, and processing conditions.

6 Experimental Recipes and Prototyping

This section details experimental protocols for prototyping both the Diamond Composite Recipe and other HDCNS-based composites.

6.1 Diamond Composite Recipe Protocol

1. Preparation of Matrix:

- Epoxidize hemp oil to produce a reactive epoxy resin.
- Synthesize hemp lignin resin through chemical modification.
- Mix the two resins in a predetermined ratio (e.g., 70:30) to form the base matrix.

2. Reinforcement Integration:

- Disperse HDCNS in a solvent using ultrasonication to achieve a uniform suspension.
- Incorporate the HDCNS suspension into the resin matrix under mechanical stirring.

3. Addition of Eco-Friendly Additives:

- Add bio-based plasticizers and cross-linking agents.
- Integrate upcycled organic waste (“trash”) as a filler.

4. Curing:

- Apply an optimized thermal curing schedule (e.g., ramping from 25°C to 150°C over several hours).
- Optionally, implement UV or catalytic curing to further reduce curing time.

6.2 Alternative Recipes for Other Matrices

Each matrix variant described in Section 4 has an associated recipe:

- **Organic Matrices (e.g., Linseed Oil Epoxy):** Follow similar steps as above with appropriate modifications in the resin synthesis and curing profile.
- **Conventional Epoxies (e.g., Bisphenol-F Epoxy):** Disperse HDCNS using high-shear mixing and apply standard curing cycles used in aerospace applications.
- **Bio-Derived Polyesters (e.g., PLA Composites):** Blend HDCNS with PLA using melt mixing and injection molding techniques.
- **Natural Rubber Matrices:** Integrate HDCNS into latex using solution mixing, followed by vulcanization.

- **Advanced Polymers (e.g., Polyimides):** Utilize high-temperature processing methods to ensure compatibility of HDCNS with the high-performance matrix.

Each experimental protocol is detailed in our open source repository to facilitate replication and further innovation.

7 Open Source Release

In the spirit of transparency and collaborative research, all recipes, experimental protocols, data sets, and analysis scripts associated with this work are released under the **Creative Commons Attribution 4.0 International (CC BY 4.0)** license. Researchers and industry practitioners can access and contribute to the project at:

<https://opensource.org/licenses/by/4.0/>

8 Potential Applications

The integration of HDCNS into composite materials opens up transformative possibilities across several industries:

- **Aerospace and Defense:** Development of lightweight, high-strength composites for aircraft, spacecraft, and military vehicles.
- **Sustainable Transportation:** Production of eco-friendly components for electric vehicles and advanced public transport systems.
- **Construction and Infrastructure:** Creation of robust building materials that reduce environmental impact.
- **Wearable Electronics:** Fabrication of flexible, conductive composites for next-generation smart textiles and devices.

9 Discussion

The *Diamond Composites Theory* and the associated experimental recipes presented herein mark a paradigm shift in composite materials engineering. By harnessing the unique properties of HDCNS and integrating them into a diverse range of matrices, we offer a versatile platform for developing sustainable, high-performance composites. Our mathematical models validate the potential for property optimization, and the open source release ensures that this technology can evolve through community-driven innovation. This comprehensive release covers not only the Diamond Composite Recipe but also all variants of HDCNS integration, making it the definitive resource in this emerging field.

10 Conclusion

We have presented a groundbreaking, comprehensive framework for the integration of hemp-derived carbon nanosheets into composite materials. The *Diamond Composites Theory* introduces novel recipes, robust mathematical models, and detailed experimental protocols for fabricating sustainable composites using HDCNS across a broad array of matrices. By open sourcing all associated data and methods under the **CC BY 4.0** license, we invite researchers and industry partners to build upon this work and accelerate the transition to eco-friendly composite materials. Future research will focus on experimental prototyping, scaling, and performance optimization, paving the way for real-world applications in high-impact industries.

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