

Guide to Hemp-Derived Carbon Nanosheets (HDCNS) Production for Composite Materials

Marie Seshat Landry

April 11, 2025

Abstract

This paper presents a comprehensive guide to the production of Hemp-Derived Carbon Nanosheets (HDCNS) for use in high-performance composite materials. Emphasizing sustainable innovation, it outlines various thermochemical, chemical, and hybrid processes to synthesize nanosheets from hemp biomass. Key methodologies, material selection, and integration into composite systems are detailed, positioning HDCNS as a viable green alternative to synthetic nanomaterials.

1. Introduction

Carbon nanosheets (CNS) are two-dimensional nanomaterials known for their exceptional mechanical, thermal, and electrical properties. Hemp, a fast-growing regenerative plant, is an ideal feedstock for carbon nanosheet production due to its high cellulose content, rapid biomass accumulation (up to 4 meters in 120 days), and carbon sequestration potential (up to 10 tons of CO₂ per hectare). Hemp-derived CNS (HDCNS) offer an organic alternative to graphene and petroleum-based nanocarbons, aligning with the goals of sustainability, biodegradability, and circular material economies.

2. Hemp Biomass Selection

2.1. Bast Fibers

High in cellulose and low in lignin, bast fibers yield well-ordered carbon frameworks with high crystallinity—ideal for advanced structural composites.

2.2. Hurds (Shivs)

Rich in lignin and hemicellulose, hurds contribute to higher porosity and tailored surface functionalities suitable for electrochemical and EMI applications.

2.3. Leaves and Whole Stalks

These parts are valuable for bulk production or hybrid composites and can be pre-treated to optimize yield and sheet morphology.

3. Methods of HDCNS Production

3.1. Pyrolytic Techniques

3.1.1 Direct Pyrolysis

- **Process:** Thermal decomposition of hemp biomass in an inert atmosphere (N_2 , Ar) between 500–1000°C.
- **Products:** Amorphous to semi-graphitic carbon nanosheets.
- **Control Parameters:** Heating rate, hold time, and biomass particle size.

3.1.2 Hydrothermal Carbonization (HTC) + Pyrolysis

- **Step 1:** HTC at 180–250°C in a sealed aqueous system.
- **Step 2:** Pyrolysis post-treatment to develop carbon structure.
- **Advantages:** Lower energy demand, enhanced sheet porosity.

3.2. Chemical Activation Techniques

3.2.1 KOH or $ZnCl_2$ Activation

- Biomass is impregnated with activating agent before pyrolysis.
- Produces high surface area nanosheets with increased conductivity.

3.2.2 Template-Assisted Activation

- Uses sacrificial templates (e.g., MgO, silica) to control sheet dimensions.
- Template removed post-carbonization using acid washing.

3.3. Mechanical and Physical Exfoliation

- Ball milling or sonication used to exfoliate pyrolyzed hemp biochar.
- Useful for controlling nanosheet thickness and lateral size.

3.4. Emerging Techniques

3.4.1 Microwave-Assisted Pyrolysis

- Rapid, uniform heating.
- Enhances graphitization at lower temperatures.

3.4.2 Plasma Treatment

- Surface-functionalizes nanosheets with oxygen or nitrogen groups.
- Can improve dispersion in polymer matrices.

4. Integration into Composite Materials

4.1. Polymer Matrix Composites (PMCs)

- Nanosheets improve tensile strength, thermal stability, and conductivity.
- Compatible with biopolymers (PLA, PHB) and synthetic resins (epoxy, PU).

4.2. Bio-composites and Green Plastics

- Fully organic matrices reinforced with HDCNS yield biodegradable, high-performance materials.
- Applications: construction panels, packaging, automotive interiors.

4.3. Multifunctional Composites

- EMI shielding, sensors, supercapacitors, and structural batteries.
- Nanosheets functionalized with dopants (N, S) to enhance properties.

5. Sustainability Considerations

- **Energy Efficiency:** Prefer low-temperature, catalytic, or microwave-assisted processes.

- **Waste Valorization:** Use agricultural waste or process residues.
- **Circular Economy:** Design composites for recyclability or biodegradability.

6. Conclusion

Hemp-derived carbon nanosheets represent a transformative material class for the green composite industry. Through various thermochemical and chemical synthesis routes, HD-CNS can be tailored for structural, electrical, and environmental applications. Integrating these bio-based nanosheets into composite technologies advances not only material performance but also ethical and ecological standards for future innovation.

References

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