

Standard Operating Procedure (SOP) for the large-scale commercial production of sustainable, organic hemp-derived carbon nanosheets (HDCNS) for integration into commercial epoxy composite materials.

This guide provides a Standard Operating Procedure (SOP) for the large-scale commercial production of sustainable, organic hemp-derived carbon nanosheets (HDCNS) for integration into commercial epoxy composite materials. The process is based on a **hydrothermal carbonization** and **activation** method, which has shown promise for scalable production and superior material properties.

Section 1: Raw Material Sourcing and Preparation

1.1. Sourcing of Organic Hemp Biomass 🌿

- **Objective:** To secure a consistent supply of high-quality, organic hemp bast fiber.
- **Procedure:**
 1. Partner with certified organic hemp farms that practice regenerative agriculture to ensure the raw material is free from pesticides, herbicides, and synthetic fertilizers.
 2. Use **hemp bast fiber**, which has a complex multi-layered structure ideal for producing carbon nanosheets ¹. Hemp bast fibers are the long, strong fibers on the outer layer of the hemp stalk.
 3. Implement a strict receiving and inspection protocol to verify the quality, moisture content, and purity of each batch.

1.2. Pre-Treatment of Hemp Bast Fiber

- **Objective:** To clean and prepare the hemp fiber for the carbonization process.
- **Procedure:**
 1. Wash the hemp bast fibers with a solvent like an ethanol-water solution to remove any impurities, such as dust, dirt, and residual plant matter ².
 2. Dry the washed fibers in a low-temperature industrial dryer at approximately **80°C** for a minimum of 24 hours to remove all moisture ².
 3. Shred or mill the dried fibers into a more uniform and manageable size to facilitate even processing in subsequent steps.

Section 2: Production of Carbon Nanosheets

2.1. Hydrothermal Carbonization

- **Objective:** To convert the organic hemp biomass into a carbon-rich char.
- **Procedure:**
 1. Load the pre-treated hemp fiber into a large-scale pressure vessel or hydrothermal reactor.
 2. Add a solvent, such as water, and seal the reactor.
 3. Heat the reactor to a temperature of approximately **180°C** for a duration of 24 hours under pressure ³. This process, known as hydrothermal carbonization, creates a carbonized material with a specific structure that is beneficial for nanosheet

formation ⁴.

4. Allow the reactor to cool slowly before safely opening and extracting the resulting hydrochar.

2.2. Chemical Activation and Pyrolysis

- **Objective:** To activate the hydrochar, increasing its surface area and creating the nanosheet structure.
- **Procedure:**
 1. Mix the hydrochar with a chemical activating agent, such as **potassium hydroxide (KOH)**. The ratio of activating agent to carbon material is a critical parameter that must be precisely controlled for optimal results ⁴.
 2. Place the mixture in a tube furnace and heat it under an inert atmosphere (e.g., nitrogen gas) ².
 3. The furnace temperature should be raised to a high temperature, typically between **500–700°C**, and held for approximately 2 hours to achieve complete carbonization and activation ². This step is crucial for developing the high specific surface area and interconnected structure of the nanosheets ¹.

2.3. Exfoliation and Purification

- **Objective:** To separate the activated carbon into individual nanosheets and remove residual chemicals.
- **Procedure:**
 1. Disperse the activated carbon material in a solution (e.g., ethanol-water) ².
 2. Use a high-intensity sonicator or ball mill to **exfoliate** the material, breaking it down into individual nanosheets ². Sonication for 1–2 hours is a common method, while ball milling for 6–12 hours can achieve a finer dispersion ².
 3. Filter and wash the resulting nanosheet dispersion to remove any remaining activating agent or other impurities.
 4. Dry the purified nanosheets for storage or immediate integration into the epoxy composite.

Section 3: Quality Control & Safety

3.1. Quality Control Protocols

- **Objective:** To ensure the final product meets the required specifications for integration into epoxy composites.
- **Procedure:**
 1. **Particle Size Analysis:** Use techniques like Transmission Electron Microscopy (TEM) and Scanning Electron Microscopy (SEM) to verify the nanosheet thickness and morphology ¹.
 2. **Surface Area Measurement:** Use the Brunauer–Emmett–Teller (BET) method to confirm the specific surface area, which is a key performance indicator ¹.
 3. **Conductivity Testing:** Measure the electrical conductivity of the nanosheet sample to ensure it meets the standards required for certain composite applications ¹.
 4. **Purity Analysis:** Use Raman spectroscopy to characterize the graphitic nature and purity of the nanosheets ².

3.2. Safety and Environmental Protocols

- **Objective:** To protect workers and the environment during the production process.
- **Procedure:**

1. **Air Quality:** Implement engineering controls such as ventilated enclosures (e.g., glove boxes, fume hoods) equipped with HEPA filters to manage airborne nanomaterial dust and minimize worker exposure ⁵.
2. **Personal Protective Equipment (PPE):** All workers must wear appropriate PPE, including respirators, gloves, and protective clothing, when handling nanomaterials ⁵.
3. **Chemical Handling:** Establish strict protocols for handling potassium hydroxide and other hazardous chemicals, including spill response plans and proper disposal procedures.
4. **Waste Management:** Treat all chemical byproducts and waste materials as hazardous waste and dispose of them according to local, state, and federal regulations ⁶.
5. **Environmental Impact:** As the process uses a renewable and carbon-negative source material, the overall environmental footprint is significantly lower than that of petroleum-based alternatives ⁷. This should be a key selling point in the final product documentation.

References

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Related Additional Readings

- **NRC Publications Archive:** Provides an in-depth look at the research behind hemp-derived carbon nanosheets and their potential applications. [Interconnected carbon nanosheets derived from hemp for ultrafast supercapacitors with high energy - NRC Publications Archive](#)
- **ASME:** Discusses the discovery that hemp carbon can be used to make supercapacitors

with superior performance. [Hemp Carbon Makes Supercapacitors Superfast - ASME](#)

- **Google Patents:** Provides a technical overview of the combined hydrothermal and activation process used to create the nanosheets. [US20140328006A1 - Carbon nanosheets - Google Patents](#)