

A Comparative Analysis of Hemp-Derived Carbon Nanosheets and Graphite-Derived Graphene as Reinforcing Agents in Synthetic and Bio-Epoxy Composites

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September 24, 2025

Abstract

This pre-experimental paper outlines a comprehensive investigation into the efficacy of hemp-derived carbon nanosheets (H-CNS) as a reinforcing agent in epoxy composites, in direct comparison to traditional graphite-derived graphene (G-G). The study will encompass the characterization of H-CNS and G-G as standalone materials, followed by their incorporation into both a conventional synthetic epoxy and a sustainable bio-epoxy resin. The primary objective is to determine if H-CNS, a potentially more sustainable and cost-effective material, can offer comparable or superior performance enhancements in terms of mechanical, thermal, and electrical properties. This research is motivated by the growing demand for advanced composite materials with improved performance and a reduced environmental footprint. The successful application of H-CNS could pave the way for a new class of high-performance, bio-based composites with broad industrial applications.

1 Introduction

Graphene, a two-dimensional allotrope of carbon, has garnered significant attention in materials science due to its exceptional mechanical, thermal, and electrical properties. Its incorporation into polymer matrices, particularly epoxy resins, has been shown to yield composites with enhanced strength, stiffness, thermal stability, and electrical conductivity. The primary source of graphene is typically high-purity graphite, which undergoes a series of chemical and mechanical exfoliation processes. However, these methods can be energy-intensive, costly, and reliant on a finite resource. In recent years, there has been a growing interest in the development of sustainable and cost-effective alternatives to graphite-derived graphene. One promising avenue of research is the synthesis of carbon nanosheets from biomass precursors. Hemp (*Cannabis sativa* L.), a versatile and rapidly growing plant, has emerged as a particularly attractive source due to its high cellulose content and fibrous structure. The conversion of hemp fibers into carbon nanosheets offers a "waste-to-wealth" approach, transforming a low-value agricultural byproduct into a high-performance nanomaterial. The resulting hemp-derived carbon nanosheets (H-CNS) are structurally similar to graphene, consisting of few-layered graphitic domains. However, they may also possess a higher degree of structural defects and a more amorphous character, which could influence their interaction with polymer matrices. The central question this research seeks to answer is whether these structural differences translate into a performance deficit or if H-CNS can serve as a viable, and perhaps even advantageous, reinforcing agent in epoxy composites. Furthermore, the increasing emphasis on sustainability in materials engineering necessitates the exploration of not only bio-derived reinforcing agents but also bio-based polymer matrices. Bio-epoxy resins, derived from renewable resources such as plant oils, offer a more environmentally friendly alternative to traditional petroleum-based epoxies. The compatibility and performance of H-CNS and G-G within these bio-epoxy systems is a critical area of investigation that remains largely unexplored. This study will therefore undertake a systematic and comparative analysis of H-CNS and G-G as reinforcing fillers in both a standard synthetic epoxy and a commercially available bio-epoxy. By characterizing the nanomaterials themselves and the resulting composites, we aim to provide a comprehensive assessment of the potential of hemp-derived carbon nanosheets as a sustainable and high-performance additive for advanced composite materials.

2 Materials and Methods

2.1 Materials

2.1.1 Carbon Nanosheet Precursors

- Hemp bast fibers (to be sourced from a local supplier)
- High-purity graphite powder (e.g., Sigma-Aldrich, 325 mesh)

2.1.2 Epoxy Resins

- Synthetic Epoxy: Bisphenol A diglycidyl ether (DGEBA) based epoxy resin (e.g., EPON™ Resin 828, Miller-Stephenson) and a corresponding amine-based hardener (e.g., EPIKURE™ Curing Agent 3223, Miller-Stephenson).
- Bio-Epoxy: A commercially available bio-epoxy resin system (e.g., Entropy Resins, Super Sap ONE).

2.1.3 Reagents for H-CNS Synthesis

- Hydrochloric acid (HCl)
- Sodium hydroxide (NaOH)
- Deionized water
- Argon gas (high purity)

2.1.4 Reagents for G-G Synthesis (Modified Hummers' Method)

- Sulfuric acid (H_2SO_4)
- Sodium nitrate (NaNO_3)
- Potassium permanganate (KMnO_4)
- Hydrogen peroxide (H_2O_2)
- Hydrazine hydrate ($\text{N}_2\text{H}_4 \cdot \text{H}_2\text{O}$)

2.2 Synthesis of Hemp-Derived Carbon Nanosheets (H-CNS)

The synthesis of H-CNS will be adapted from the procedure described by Wang et al. (2013).

1. **Pre-treatment of Hemp Fibers:** Raw hemp bast fibers will be washed with deionized water and dried. The fibers will then be treated with a dilute HCl solution to remove hemicellulose, followed by a dilute NaOH solution to remove lignin. The purified cellulose fibers will be washed thoroughly with deionized water until a neutral pH is achieved and then dried.
2. **Pyrolysis:** The dried cellulose fibers will be placed in a tube furnace and pyrolyzed under an argon atmosphere. The furnace will be ramped to a temperature of 800-1000 °C and held for 1-2 hours.
3. **Activation (Optional):** A portion of the pyrolyzed carbon will be subjected to a chemical activation process using KOH to increase surface area and porosity.
4. **Characterization:** The resulting H-CNS will be characterized using the techniques outlined in section 2.5.

2.3 Synthesis of Graphite-Derived Graphene (G-G)

Graphene will be synthesized from graphite powder using a modified Hummers' method.

1. **Oxidation of Graphite:** Graphite powder will be added to a cooled solution of concentrated H_2SO_4 and NaNO_3 . KMnO_4 will be added gradually while keeping the temperature below 20°C . The mixture will be stirred for 24 hours.
1. **Reduction of Graphene Oxide:** The resulting graphite oxide will be treated with H_2O_2 and then washed repeatedly with distilled water.
1. **Characterization:** The synthesized G-G will be characterized as described in section 2.5.

2.4 Fabrication of Epoxy Composites

1. **Dispersion of Nanosheets:** H-CNS and G-G will be dispersed in the epoxy resin (both synthetic and bio-epoxy) at various weight percentages (e.g., 0.1, 0.5, 1.0 wt %).
2. **Degassing:** The mixtures will be degassed in a vacuum oven to remove any entrapped air bubbles.
3. **Curing:** The appropriate amount of hardener will be added to the epoxy-nanosheet mixture and thoroughly mixed. The mixture will then be poured into molds and cured according to the manufacturer's specifications.
4. **Control Samples:** Neat epoxy samples (without any nanosheet reinforcement) for both the synthetic and bio-epoxy systems will also be prepared for baseline comparison.

2.5 Characterization Techniques

2.5.1 Characterization of H-CNS and G-G

- **Raman Spectroscopy:** To assess the structural quality, number of layers, and defect density of the carbon nanosheets.
- **X-ray Diffraction (XRD):** To determine the interlayer spacing and crystalline structure.
- **Transmission Electron Microscopy (TEM):** To visualize the morphology and nanostructure of the nanosheets.
- **Brunauer-Emmett-Teller (BET) Analysis:** To measure the specific surface area and pore size distribution.

2.5.2 Characterization of Epoxy Composites

- **Tensile Testing:** To determine the Young's modulus, ultimate tensile strength, and elongation at break of the composites according to ASTM D638.
- **Flexural Testing:** To measure the flexural strength and modulus according to ASTM D790.
- **Impact Testing:** To evaluate the impact resistance of the composites (e.g., Izod or Charpy test).
- **Dynamic Mechanical Analysis (DMA):** To investigate the viscoelastic properties of the composites and determine the glass transition temperature (T_g).
- **Thermogravimetric Analysis (TGA):** To assess the thermal stability and degradation behavior of the composites.
- **Four-Point Probe Measurement:** To determine the electrical conductivity of the composites.
- **Scanning Electron Microscopy (SEM):** To examine the fracture surfaces of the composites and assess the dispersion and interfacial adhesion of the nanosheets within the epoxy matrix.

3 Anticipated Results

3.1 Characterization of H-CNS and G-G

It is anticipated that Raman spectroscopy will confirm the graphitic nature of both H-CNS and G-G, with the D and G bands providing information on the level of disorder and graphitization. G-G is expected to exhibit a sharper 2D band, indicative of fewer layers and higher crystalline quality compared to H-CNS. XRD analysis is expected to show a characteristic peak for G-G corresponding to the (002) plane of graphite, while H-CNS may exhibit a broader peak, suggesting a more amorphous structure. TEM imaging will likely reveal the layered structure of both materials, with G-G appearing as thin, transparent sheets and H-CNS potentially showing a more crumpled or aggregated morphology.

3.2 Mechanical Properties of Composites

The addition of both H-CNS and G-G is expected to increase the tensile strength, Young's modulus, and flexural properties of both the synthetic and bio-epoxy composites. It is hypothesized that G-G, due to its higher aspect ratio and pristine structure, will provide a greater degree of reinforcement at lower concentrations. However, the potential for better dispersion and interfacial adhesion of H-CNS, due to its surface functionalities, may lead to comparable or even superior mechanical properties at higher loading levels. The impact strength of the composites is also expected to improve with the addition of the nanosheets.

3.3 Thermal Properties of Composites

The thermal stability of the epoxy composites, as determined by TGA, is expected to be enhanced by the incorporation of both H-CNS and G-G. The nanosheets can act as a barrier to the diffusion of volatile degradation products. DMA results are anticipated to show an increase in the storage modulus and glass transition temperature of the composites, indicating improved thermomechanical performance.

3.4 Electrical Properties of Composites

A significant increase in the electrical conductivity of the epoxy composites is expected with the addition of both types of carbon nanosheets. It is anticipated that a percolation threshold will be observed, above which the conductivity increases dramatically. G-G is expected to achieve this percolation threshold at a lower concentration than H-CNS due to its higher intrinsic conductivity and more extended graphitic domains.

3.5 Morphology of Composites

SEM analysis of the fracture surfaces is expected to provide insights into the dispersion of the nanosheets and their interaction with the epoxy matrix. Good dispersion and strong interfacial adhesion will be indicated by a rough fracture surface with evidence of nanosheet pull-out. Agglomeration of the nanosheets will likely lead to premature failure and will be visible as clumps or voids in the fracture surface.

4 Discussion

[PLACEHOLDER FOR RESEARCHER: Interpret the findings from the characterization of H-CNS and G-G. How do the structural differences between the two materials potentially influence their performance as reinforcing agents? Analyze the mechanical, thermal, and electrical properties of the composites. Do the results support the alternative hypothesis that H-CNS can be a viable replacement for G-G? How does the performance of the nanosheets differ between the synthetic and bio-epoxy matrices? Discuss the observed dispersion and interfacial adhesion from the SEM images and correlate these observations with the measured properties. What are the limitations of this study, and how might they have affected the results? Consider any unexpected outcomes and propose possible explanations.]

5 Conclusion

[PLACEHOLDER FOR RESEARCHER: Summarize the main findings of the study in one or two sentences. What are the key takeaways regarding the potential of hemp-derived carbon nanosheets in epoxy composites? What are the broader implications of this work for the development of sustainable and high-performance composite materials? Based on the limitations and findings of this study, what specific experiments or research directions should be pursued next?]

References

- [1] Wang, H., et al. (2013). Interconnected carbon nanosheets derived from hemp for ultrafast supercapacitors with high energy. *ACS Nano*, 7(6), 5131-5141. DOI: 10.1021/nn400731g
- [2] Hummers Jr, W. S., Offeman, R. E. (1958). Preparation of graphitic oxide. *Journal of the American Chemical Society*, 80(6), 1339-1339. DOI: 10.1021/ja01539a017
- [3] Graphene in Epoxy Composites: A Review. (A relevant and recent review article will be cited here).
- [4] Bio-based Epoxy Resins: A Review. (A relevant and recent review article will be cited here).