Performance improvement as a battery material of carbon black synthesized through thermal plasma-based methane pyrolysis

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Abstract: Plasma-based methane pyrolysis is a clean method for producing hydrogen and carbon black but faces energy cost challenges. To compensate for this, carbon black should be applied to value materials. In this study, the properties of carbon black were enhanced using various post-processing methods and tested in actual battery applications, demonstrating performance comparable to commercial materials.

1. Introduction

Global warming caused by extensive energy use has led to efforts to reduce greenhouse gases, including methane, a major contributor to climate change. Plasma-based methane pyrolysis is an eco-friendly technology that breaks down methane without CO_2 emissions, producing hydrogen and valuable carbon black. Thermal plasma is efficient and scalable, converting methane into materials like carbon black, but its high energy cost requires offsetting through high-value application [1]. Post-treatment methods, such as heat and chemical treatments, improve carbon black surface area, conductivity, and stability. This study used a triple DC thermal plasma system and post-treatment to produce carbon black, showing battery performance comparable to commercial Super-P, offering a sustainable solution.

2. Methods

Methane pyrolysis was conducted using a triple DC thermal plasma system, with the high-temperature zone optimized for efficient methane conversion. The synthesized carbon black was post-treated using three methods: annealing, chemical treatment, and a combination of both, chemical annealing (CA). Coin cells were fabricated to evaluate the electrochemical performance of the treated carbon black as a conductive agent for batteries. Main properties of the carbon black were analyzed using GC-MS and TGA for impurity detection, and XRD, TEM, Raman spectroscopy, BET, and a powder resistivity for structural and electrical characteristics [2].

3. Results and Discussion

Figure 1 shows the removal of impurities from carbon black for each post-treatment method. Non-treated carbon black contained significant amounts of PAHs, such as $C_{16}H_{10}$, $C_{17}H_{12}$, $C_{18}H_{10}$, $C_{20}H_{12}$, and $C_{22}H_{12}$, formed by incomplete combustion during methane pyrolysis. Chemical treatment alone slightly reduced these impurities, as shown by decreased peak intensities. Annealing at 1500℃ further reduced the PAHs peaks significantly, indicating effective impurity removal. The chemical annealing showed even lower peak intensities than annealing alone, demonstrating that chemical treatment enhances surface activation, facilitating more effective impurity removal during annealing.

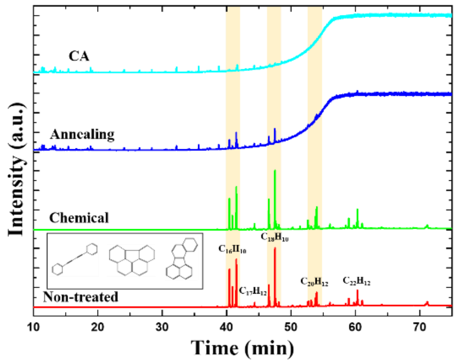

Fig. 1. GC-MS result of non-treated, chemical treatment, annealing, and chemical annealing samples.

The removal of these impurities improved the properties of the carbon. For example, the surface area increased from 36.54 m²/g to 120.38 m²/g, and the electrical conductivity rose from 1.5 S/cm to 17.5 S/cm under chemical annealing conditions. When applied to a battery, it achieved a capacity of 334.58 mAh/g, comparable to commercial materials.

4. Conclusion

This study synthesized hydrogen and carbon black via methane pyrolysis using a triple DC thermal plasma system, achieving over 95% methane conversion, 85% hydrogen selectivity without CO_2 emissions. Chemical annealing significantly improved carbon black properties, increasing surface area to 120.38 m²/g and enhancing conductivity. Chemical annealing treated carbon black demonstrated battery performance comparable to commercial Super-P, with a capacity of 334.58 mAh/g. These findings highlight the potential of eco-friendly carbon black for Li-ion batteries.

References

[1] M. Gautier *et al.*, Int. J. Hydrog. Energy, **42**, 28140-56 (2017).
[2] Lee *et al.*, Int. J. Hydrogen Energy, 48, 27127-36 (2023).