Integrated Process for the Synthesis of Carbon–Silicon Nanocomposites from Biowaste and Metallurgical Sludge

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Abstract

This study presents an integrated and sustainable technology for producing nanostructured carbon–silicon composite materials from renewable biomass feedstock (rice husk) combined with industrial waste residues. The proposed approach aims to address both waste valorization and the development of advanced functional materials for next-generation energy storage systems. The synthesis process involves consecutive stages of carbonization, activation, and demineralization, resulting in the formation of a highly porous structure with a well-developed specific surface area. Carbonization was carried out in an inert CO_2 atmosphere at temperatures ranging from 300 to 1000 °C, followed by physical activation in the range of 600 to 1200 °C. Subsequent removal of mineral impurities was achieved using a modified Soxhlet extraction technique, which ensured effective purification of the final product. The obtained silicon dioxide was predominantly in an X-ray amorphous state, exhibiting a diff use peak maximum at $2\theta = 24°$, with a specific surface area of 120–150 m^2/g and a pore volume of 0.5–0.8 cm^3/g. XRF elemental analysis confirmed a SiO_2 purity level of up to 99.7%. SEM imaging revealed spherical particles with an average diameter of ~50 nm and a uniform distribution, while FTIR spectroscopy confirmed the preservation of characteristic siloxane (Si–O–Si) bonds. The developed approach demonstrates a promising route for converting low-cost biomass and waste resources into high-value carbon–silicon materials suitable for use in electrochemical energy storage and other advanced technological applications.

Keywords

Carbon–silicon materials, rice husk, carbonization, activation, nanostructuring, amorphous silica, waste utilization, energy storage devices.

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