Mill scale-derived hematite as a low-cost supercapacitor electrode material

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Energy has become an increasingly critical need in modern societies. Sectors such as industry, transportation, agriculture, and healthcare rely on a continuous power supply, making energy production and management a strategic priority. In this context, the efficient storage and reuse of energy through high-performance storage systems have gained great importance [1].

Due to the limitations of conventional storage systems like lithium-ion and lead-acid batteries, supercapacitors have attracted growing interest as next-generation electrochemical energy storage devices. Their key advantages include long cycle life (>1000 cycles), lightweight structure, fast charge-discharge capability, and reliable operation over a wide temperature range [2]. Transition metal oxides are commonly used as electrode materials in supercapacitors because their multiple oxidation states enable redox reactions that enhance specific capacitance and energy density [3]. However, their high production cost limits commercial use. Utilizing recycled waste-derived materials as electrodes offers a cost-effective and environmentally sustainable alternative [4,5].

Mill scale is a brittle layer of iron oxide formed on steel surfaces during high-temperature processes such as hot rolling or heat treatment. It mainly consists of FeO, Fe_3O_4, and Fe_2O_3, depending on the processing conditions [6]. Although often treated as waste, its high iron oxide content makes it a promising low-cost electrode material for energy storage applications.

In the present study, mill scale was subjected to chemical treatment using sulfuric acid (H_2SO_4) solutions to leach iron ions. The pH of the resulting solution was carefully adjusted to facilitate the precipitation of iron hydroxide. Subsequently, a thermal treatment was applied to convert the precipitate into hematite (Fe_2O_3). The structural and morphological properties of the synthesized Fe_2O_3 were characterized using X-ray diffraction (XRD) and scanning electron microscopy (SEM) analyses, which provided insights into its crystallographic phases and surface morphology, respectively. The obtained Fe_2O_3 was then utilized as an active electrode material in the fabrication of asymmetric coin-cell supercapacitors. The electrochemical performance of the assembled supercapacitors was systematically evaluated through a series of electrochemical techniques, including cyclic voltammetry (CV), electrochemical impedance spectroscopy (EIS), and galvanostatic charge-discharge (GCD) measurements. These analyses were employed to assess key performance metrics such as specific capacitance, charge-discharge capability, and the cycling stability of the Fe_2O_3-based supercapacitors.

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