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Soft Magnetic Behavior and Multifunctional Performance of Mn–Zn Ferrite/MWCNT Nanocomposites for Energy Storage and Photocatalysis

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$Mn_{0.7}Zn_{0.3}Fe_2O_4$/MWCNT nanocomposites were synthesized through a combined chemical co-precipitation and ultrasonication route to examine the effect of carbon nanotube incorporation on the magnetic and multifunctional properties of Mn-Zn ferrite. X-ray diffraction confirmed that the cubic spinel ferrite phase remained preserved after MWCNT addition, while HRTEM showed ferrite nanoparticles uniformly embedded within the nanotube network. A gradual reduction in crystallite size from 8.22 nm for pristine ferrite to 7.45 nm for the 15 wt% MWCNT composite indicates that nanotubes restrict particle growth and alter the local lattice environment. Magnetic measurements showed that all samples retain soft magnetic character, with low coercivity, low remanence, and S-shaped hysteresis loops. The saturation magnetization decreased from 42.74 emu g^{-1} for pristine Mn-Zn ferrite to 24.15 emu g^{-1} for the 15 wt% MWCNT composite, mainly due to dilution of the magnetic phase by non-magnetic nanotubes and stronger interfacial effects in the hybrid structure. Electron paramagnetic resonance supported these observations through changes in resonance field, linewidth, and g-factor from 2.16 to 2.04, indicating modification of spin dynamics, local crystal field symmetry, and exchange interactions in the nanocomposites. Importantly, this magnetic tuning is accompanied by strong functional enhancement. The 15 wt% MWCNT composite delivered the best electrochemical performance, with a specific capacitance of 1533.07 F g-1 at 10 mV s-1, and also achieved 86.66% photocatalytic degradation of methylene blue. These results show that controlled incorporation of MWCNTs not only tailors the soft magnetic response of Mn-Zn ferrite, but also improves charge transport and catalytic activity. The developed nanocomposites therefore offer strong potential for multifunctional ferrite-based systems in magnetically responsive energy-storage devices and smart environmental technologies, and advanced hybrid materials.

Keywords: Ferrite; Nanocomposite; magnetic properties; supercapacitor; photocatalysis; methylene blue degradation

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