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Surface Modification of Waste-Derived Hematite Pigments with Nano-Oxides for Enhanced Colloidal and Optical Properties

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Abstract

The development of high-performance pigments from industrial by products is a key step toward a circular economy in the coatings industry. This study investigates the synthesis of hematite (α-Fe_2O_3) pigments from waste-derived iron(II) sulfate using a microwave-assisted method and their subsequent surface modification with TiO_2, SiO_2, and Al_2O_3 nanoparticles. The base pigments, synthesized at varying pH levels (8, 10, and 12), exhibited distinct morphologies, including well-defined cubic and highly faceted structures. To prevent secondary agglomeration and tailor surface reactivity, a mechanical coating process via milling was employed.

Results from SEM and DLS analyses confirm the successful deposition of nano-additives, leading to a 2.5 to 11-fold reduction in mean particle size compared to the base pigments. While the modifications significantly improved dispersibility and reduced oil absorption (particularly with 10 wt% Al_2O_3), the intrinsic red color of the hematite remained visually consistent, with ΔE values typically remaining below the threshold of perceivable change. Furthermore, electrokinetic studies revealed that nano-oxide selection allows for precise tuning of the isoelectric point (IEP), ranging from strongly acidic (IEP $\approx$ 2.6 for SiO_2) to basic (IEP > 9 for Al_2O_3). These findings demonstrate an efficient route to producing sustainable, functionalized pigments with tunable surface properties suitable for advanced industrial coatings.