Few-Layer *h*-BN/Polymer Composite Coatings for Hydrogen Barrier Protection of Steel in Future H_2 Infrastructure

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The deployment of hydrogen as an energy vector requires the development of advanced materials capable of mitigating hydrogen embrittlement and permeation in metallic infrastructures.[1] In this work, we report the design of polymer-based barrier coatings incorporating few-layer hexagonal boron nitride (FL*h*-BN) flakes as functional fillers for the protection of steel substrates under hydrogen exposure conditions. The FL*h*-BN flakes are produced via scalable wet-jet milling exfoliation, enabling industrially relevant quantities of high-quality two-dimensional materials.[2]

Building on prior demonstrations of FL*h*-BN-enhanced encapsulants for corrosion protection[3,4] and environmental barrier applications,[5] we formulate composite coatings based on highly impermeable polymer matrices combined with the intrinsic atomic impermeability, chemical inertness, and electrical insulation of FL*h*-BN. The incorporation of FL*h*-BN induces a tortuous diffusion pathway for small molecules, significantly reducing the permeation of hydrogen as well as corrosive species. The formulation of the ink is tailored to improve compactness and the adhesion on steel substrates, and the rheology is optimized for scalable and automating deposition techniques, i.e. doctor blade and spray coating.

Preliminary electrochemical corrosion tests and hydrogen barrier characterization demonstrate a drastic reduction in molecules and ions transmission rates, including hydrogen. We demonstrated that the performances of the coating are linked to the morphology, dispersion, and loading of the 2D filler, i.e., FL*h*-BN. In analogy with encapsulation systems developed for perovskite solar cells,[5,6] the composite coatings also benefit from improved thermal management and mechanical properties, which are critical for long-term operation under fluctuating pressure and temperature conditions.

Importantly, this approach enables the retrofitting of existing steel infrastructure, such as methane pipelines and storage tanks, by applying conformal barrier coatings, thereby mitigating hydrogen-related degradation without requiring the deployment of entirely new transport systems. This represents a cost-effective alternative to dedicated hydrogen infrastructure based on expensive composite materials (e.g., GFRP or CFRP), significantly lowering the barrier to large-scale hydrogen adoption.

These results highlight the potential of FL*h*-BN/polymer composites as scalable, multifunctional barrier coatings for next-generation hydrogen transport and storage, enabling safer, more durable, and economically viable pathways for the transition to the hydrogen economy.

References

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