Advancing Graphene-Enabled Materials for Scalable and Sustainable Infrastructure Systems

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Abstract

Graphene and graphene-derived nanomaterials have emerged as promising enablers for next-generation infrastructure systems due to their exceptional mechanical strength, electrical conductivity, barrier properties, and tunable surface chemistry. These attributes position graphene as a multifunctional additive capable of enhancing durability, sustainability, and performance across a wide range of civil and environmental engineering applications. This presentation presents an overview of recent advances in the integration of graphene oxide (GO), reduced graphene oxide (rGO), and graphene nanoplatelets (GNPs) into asphalt, cementitious materials, and membrane-based water treatment systems, with emphasis on scalability and real-world deployment.

In asphalt systems, low dosages of graphene-based materials have been shown to significantly improve rutting resistance, fatigue life, and resistance to oxidative and ultraviolet aging. These improvements are attributed to enhanced binder stiffness, improved stress distribution, and increased resistance to microstructural degradation. Such enhancements translate directly to longer pavement service life and reduced maintenance costs. In cementitious systems, graphene derivatives facilitate accelerated hydration kinetics, densification of the microstructure, and improved crack resistance. Additionally, they enhance barrier properties against chloride ingress and moisture penetration, thereby mitigating corrosion of steel reinforcement. These effects open opportunities for reducing cement content and lowering the carbon footprint of concrete while maintaining or improving performance. Graphene-enabled membranes represent another transformative application, particularly in water filtration and desalination. Functionalized graphene oxide laminates and hybrid nanocomposite membranes demonstrate high permeance, selective ion rejection, and improved resistance to fouling. These features make them attractive candidates for addressing critical challenges in water scarcity and environmental remediation.

However, despite significant laboratory-scale progress, challenges remain in achieving uniform dispersion, scalable manufacturing, long-term durability, and cost competitiveness. To address these barriers, this presentation identifies key research and development priorities, including the establishment of standardized material specifications, development of scalable mixing and processing techniques, and implementation of comprehensive techno-economic and life-cycle assessments. Furthermore, pilot-scale demonstration projects and field validation studies are essential to bridge the gap between laboratory innovation and industry adoption. The Center for Graphene Research and Innovation (CGRI) is actively leading efforts in this domain by integrating advanced materials characterization, pilot-scale testing, and strategic partnerships with industry and government agencies. The findings highlight the importance of coordinated, multidisciplinary collaboration to accelerate the deployment of graphene-enabled technologies. By aligning scientific innovation with practical engineering implementation, graphene-based materials have the potential to significantly enhance the resilience, sustainability, and longevity of infrastructures.

References

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