Graphene-Cellulose Hydrogels: An Apt Combination

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Graphene-cellulose hydrogels have been extensively studied in the field of functional hydrogels. This editorial presents an overview of graphene-based and cellulose-derived materials, highlighting the unique characteristics of these two materials and the synergistic advantages achieved by combining them to construct graphene-cellulose composite hydrogels. The aim is to provide novel insights for developing functional cellulose-based hydrogels enabled by carbon nanomaterials.

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Why Graphene

The initial impetus behind the graphene revolution stemmed from the quest for novel electronic materials capable of supplanting silicon. Since graphene was successfully prepared by Professor Novoselov and Geim in 2004 through mechanical stripping, the research of graphene nanocomposites has received extensive attention and research (Novoselov *et al.* 2004). Graphene, a single-layer two-dimensional nanocarbon material, possesses a closely arranged hexagonal honeycomb structure composed of sp^2 hybrid carbon atoms. Due to the abundant internal free π electrons, graphene exhibits remarkably high electron mobility and also showcases an extremely high surface area-to-volume ratio owing to its unique atomic structure in two dimensions and lamellar nano-size effect (Stoller *et al*. 2008). With exceptional mechanical properties (Lee *et al.* 2008), thermal conductivity (Balandin *et al.* 2008), and optical permeability (Nair *et al.* 2008), various novel graphene composites have been continuously developed. It is these distinctive properties that render graphene highly promising as a functional additive for constructing advanced materials. However, it should be noted that pristine graphene lacks functional groups, making it challenging to achieve sufficient dispersion in solvents while exhibiting weak binding force and compatibility with mixed matrix. Therefore, modified forms of graphene such as graphene oxide possess numerous oxygen-containing functional groups capable of interacting with composite matrices (Tang *et al.* 2012). Currently, research related to graphene has become a prominent focus area with further exploration required for its diverse applications.

Why Cellulose

Over the past decades, the use of petroleum-based materials has caused severe environmental pollution. The growing concerns regarding harmful ecological pollution and depletion of fossil-based resources have led to an acceleration in research on biomass-based materials. Meeting the demand for high-performance graphene-based macrostructure with multifunctionality is a significant challenge. Fortunately, adopting sustainable and scalable biomass feedstock may be a wise choice to support graphene-based materials. Cellulose, liberated from lignocellulosic biomass by chemical, mechanical, and/or biological methods, with renewable, degradable, and being easily accessible qualities, is a promising natural bio-polymer (Mboowa 2021). It is considered an ideal candidate for replacing petroleum-based materials in the background of "double carbon" strategy in China. Nowadays, it has been widely used in several areas, including pulp and papermaking engineering, sustainable packaging, cosmetics, food, and pharmaceutical industries, *etc*. Encouragingly, cellulose can become versatile, driven by fiber-engineering (Shen *et al.* 2010). Cellulose exhibits flexible processability, such that its size can be transformed from micron to nanometre scale, with corresponding products such as CNF, and CNC. The corresponding cellulose-based derived materials can exhibit higher crystallinity, larger aspect ratio, and favorable Young's modulus, which allow them to be effectively combined with other materials to construct multifunctional composites. What's more, the hydroxyl group in cellulose allow functionalizing the cellulose and promoting the generation of cellulosic functional composites (Hubbe *et al.* 2023). Thus, cellulose exhibits great promise in applications where graphene-based materials necessitate exceptional sustainability, flexibility, and specific micro/nanostructures, building a platform for the functional application of graphene. The synergistic combination of graphene and cellulose is mutually beneficial and addresses the limitations inherent in graphene or cellulose single component, thereby enabling their utilization in multifunctional applications.

A Perfect Combination: Graphene-Cellulose Hydrogel

Cellulose-based hydrogels, consisted with hydrophilic polymer chains and lots of dispersed water, are one of the most appealing sustainable soft materials owing to their high hydrophilicity, chemical reactivity, and structural designability, among other peculiarities (Wei *et al.* 2022). However, conventional cellulose-based hydrogels possess limitations that impede their further applications, such as poor electrical conductivity, single performance, and weak strength and toughness. Fortunately, the incorporation of graphene-based materials as functional additives in polymer hydrogels has been documented to confer exceptional properties on the composite hydrogels across various aspects (Gan *et al.* 2019; Zheng *et al.* 2020; Wang *et al.* 2023). Moreover, it is worth noting that the optimal combination of cellulose-based and graphene materials overcomes the limitations associated with traditional petroleum-derived substrate materials in terms of degradation, while conductive biobased products derived from cellulose-based materials exhibit immense potential for development due to their degradable, environmentally friendly, and sustainable characteristics. The successful example of combining graphene with cellulose-based hydrogel to create satisfying graphene-cellulose combined hydrogel products sheds light on nano-enabled cellulose-based soft materials. The design concept centered on the graphene-cellulose composite hydrogel serves as a valuable reference for interdisciplinary and development.

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