Development of High-Strength Multilayer Water Pipes Based on Recycled PE and CFRP Composites for a Circular Economy

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순환경제 기반 폐PE·CFRP 복합재를 이용한 고강도 다층 수도관 개발에 관한 연구

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Abstract

The global production and accumulation of plastic have risen dramatically over the past decades, driving a large and growing stream of plastic waste: recent syntheses estimate annual plastic waste generation on the order of hundreds of millions of tonnes per year (approximately 350–435 million tonnes), with only a small fraction actually recycled and a non-negligible amount leaking into aquatic ecosystems. Polyethylene (PE), including high-density and low-density grades, constitutes a major fraction of polymer demand and production (PE production exceeding roughly 100 million tonnes annually and accounting for a large share of global polymer use), which makes PE-based waste a dominant component of municipal and industrial plastic streams. At the same time, carbon fiber reinforced polymer (CFRP) materials are rapidly expanding in high-value sectors (a global CFRP market on the order of 100–150 kilotonnes in recent years), and end-of-life and manufacturing scrap from CFRP is projected to increase substantially, some studies project cumulative or annual CFRP waste rising into the tens to hundreds of kilotonnes (and long-term projections to 2050 are much larger) posing disposal and environmental challenges because CFRP's thermoset resin matrices are cross-linked and not readily re-meltable. These combined waste streams (polyethylene's ubiquity and CFRP's increasing end-of-life burden) create both environmental problems, landfill pressure, microplastic formation, and difficult-to-manage composite waste—and lost economic value when high-quality polymers and reinforcing fibers are discarded rather than recovered. Given polyethylene's good processability and favorable mechanical and chemical resistance characteristics, and CFRP's high specific strength and stiffness, integrating recycled PE and reclaimed CFRP into engineered, multilayer pipe structures offers a route to convert low-value waste into high-performance, durable infrastructure materials, reducing environmental burden while adding economic and functional value.

This study develops a high-performance, multilayer water pipe by valorizing post-consumer polyethylene and recycled carbon fiber reinforced plastic. Discarded PE items and CFRP scrap are collected, sorted, and subjected to pretreatment (contaminant removal, size reduction, washing, and drying). The cleaned PE feedstock is melt-blended with controlled fractions of mechanically/chemically reclaimed CFRP and tailored additives (coupling agents and processing aids), and then processed via co-extrusion to form a multilayer pipe architecture in which an engineered core or reinforcement layer contains the recycled CFRP-rich compound while inner and outer PE-dominant layers provide corrosion resistance, hydraulic smoothness, and weldability. The processing route is optimized to ensure dispersion of reclaimed fibers, interfacial adhesion, and layer integrity; mechanical (tensile, burst, impact), thermal, and long-term durability tests are performed to benchmark the composite pellets and extruded pipes against commercial standards. By demonstrating scalable extrusion processing and improved specific mechanical properties through recycled CFRP reinforcement, the proposed approach aims to (1) divert significant volumes of PE and CFRP from landfills, (2) produce value-added infrastructure products that meet or exceed performance requirements for potable and non-potable piping, and (3) advance circular-economy pathways for polymer and composite waste in line with sustainable materials management goals.

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