Circular Thermoplastic Composites Enabled by Sustainable Nanoengineering of Graphene and 2D materials for Lightweight, Functional Aerospace and Automotive Applications

Prof. Dr. Burcu Saner Okan[1,2]
[1] *Sabancı University, Faculty of Engineering and Natural Sciences, Materials Science and Nanoengineering, Tuzla 34956, Istanbul, Turkiye*
[2] *Sabanci University Composite Technologies Center of Excellence and Integrated Manufacturing Technologies Research and Application Center (SU-IMC), Teknopark Istanbul, 34906 Pendik, Istanbul, Turkiye*
burcu.saner@sabanciuniv.edu

Under the climate crisis and transport-sector decarbonisation mandates, lightweight and circular thermoplastic composites are being prioritised to deliver functional, lower-emission parts. The use of graphene and other 2D materials is emphasised so that property gains can be realised without major changes to existing tooling and processes, enabling controlled part manufacture in aerospace and automotive applications. In the present work, sustainable conversion pathways were developed in which thermoplastic wastes (e.g., PET, PP) and thermoset wastes (e.g., waste tyres) were upcycled into graphene structures; dimensional and physico-chemical attributes were tuned via a patented thermo-chemical production route. The resulting graphene is then used to create high-performance composite materials by combining it with recycled plastics, natural fibers (such as hemp and flax), and recycled carbon fibers obtained from wind turbines. Through controlled functionalisation and dispersion, interphase quality was enhanced and pathways for thermal, electrical, and mechanical improvements were established across commodity, engineering, and high-performance matrices, while industrial compatibility was maintained with twin-screw and thermokinetic compounding, film extrusion, injection and compression moulding, and additive manufacturing.
Industry-led demonstrations were executed and validated through part-manufacturing tests using waste-derived graphene and other 2D materials across the thermoplastic performance pyramid via selective processing. In automotive applications, a front-end carrier—a structural carrier that houses the integrated system of major vehicle modules, including the cooling module, hood latch (HL), headlamp modules, and bumper beam—achieved a ~10 wt% mass reduction by partially substituting long glass fibre with a waste-tyre-derived graphene masterbatch in PP matrix. In aerospace applications, the incorporation of hexagonal boron nitride into PEEK raised thermal conductivity to 12.45 W/(m·K) in-plane and 2.13 W/(m·K) through-plane, while processability was retained for film extrusion, injection moulding, and additive manufacturing to address thermal-management needs. A cradle-to-gate life-cycle assessment was applied so that CO_2-equivalent impacts were quantified and performance–cost–carbon trade-offs were identified, thereby supporting the adoption of eco-design and a circular-economy approach through CO_2-emission reduction and addressing carbon-tax considerations.