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Additive Manufacturing and Characterization of PEKK/Martian-Regolith Composite for Lightweight and Sustainable Space Applications

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Abstract

Progress in sustainable resource utilization and advanced manufacturing technologies is being propelled by initiatives aimed at establishing human settlements on Mars, such as SpaceX's Occupy Mars program. One key strategy involves the development of materials and processes that leverage in-situ Martian resources. This study focuses on the characterization of Poly-Ether-Ketone-Ketone (PEKK) reinforced with 10% Martian Regolith Simulant (MRS) for sustainability applications in space. A conceptual Mars rover wheel is designed and manufactured using this composite material. The process begins with the pulverization of amorphous PEKK and the sieving of Martian Regolith Simulant to achieve a particle size below 100 microns. These components are blended and processed using a twin-screw extruder to produce a filament with a uniform diameter, suitable for Fused Deposition Modeling (FDM) 3D printing. Established protocols from previous studies are applied to optimize FDM parameters for amorphous PEKK, followed by an annealing process to enhance crystallization and mechanical performance of the printed parts. The quality of the filament manufacturing process is assessed through Scanning Electron Microscopy (SEM), Thermogravimetric Analysis (TGA), and density measurements, ensuring uniform dispersion of Martian regolith within the PEKK matrix. The mechanical properties of the PEKK/MRS composite are evaluated using tensile, 3-point bending, and Dynamic Mechanical Analysis (DMA) tests. These analyses confirm the feasibility of producing high-quality, mechanically robust 3D-printed components using the PEKK/MRS composite. Based on these findings, a Mars rover wheel with a graded metamaterial structure is designed. This approach not only incorporates in-situ resource utilization but also employs a lightweight geometric configuration that minimizes material usage while preserving structural integrity. The integration of material characterization with structural design presents a promising pathway for sustainable manufacturing solutions tailored to Martian exploration and habitation. Ultimately, this study highlights the potential of utilizing additive manufacturing techniques in conjunction with locally sourced materials to address sustainability and material efficiency challenges in extraterrestrial environments.