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Author: Mr. Henrik Øvrebø
Norwegian University of Science and Technology, Norway

HIGH-PERFORMANCE POLYMERS VIA ADDITIVE MANUFACTURING AS A NEWSPACE PROTOTYPING TOOL

Abstract

Aim: As space missions become more complex and frequent, the demand for faster prototyping and cost-effective manufacturing processes has become critical. Decreased development time and cost are essential for rapid prototyping to enable agile hardware methodology in the space sector. Additive Manufacturing (AM) via Material Extrusion (MEX) has recently gained traction as a low-cost prototyping tool in structural applications due to the introduction of commercial high-performance polymers (HPP), substantially increasing the mechanical strength of the producible components. Despite some inherent downsides to the technology, this research hypothesizes that in some space applications like small satellites in zero-g, these downsides are manageable, and component developments from HPP produced with AM are a viable path for the industry to explore. This paper examines how high-performance materials in AM can decrease development costs while adhering to strict space requirements. Methodology: To explore this hypothesis, a comparative case study was conducted using an identical CubeSat structure made from aluminum, Nylon-Carbon fiber (PA6-CF), and PEEK-carbon fiber (PEEK-CF). This design comparison evaluates cost and time parameters. As PA6-CF is not an established space polymer, two successive thermal vacuum outgassing (TVAC) experiments were performed on ISO527 PA6-CF specimens to measure total mass loss (TML), the bake-out effect of TVAC, and tensile strength. The structures were also vibration tested with a sine sweep test between 1hz and 400hz. The case study design was also modified with generative design (GD) with design for additive manufacturing (DfAM) and validated through a random vibration response (RVR) simulation.

Results: Using GD with DfAM with iterative design optimization through RVR, HPPs like PA6-CF can achieve a comparable structural performance to aluminum with substantially reduced costs and production times, positioning it as an ideal material for rapid prototyping. The outgassing tests revealed that pre-baking reduced volatile compound release with an acceptable TML, while the tensile tests showed strength increase post TVAC.

Conclusion: This study demonstrates that additive manufacturing with PA6-CF offers a viable, cost-effective method for rapid satellite prototyping. Leveraging DfAM, reduced component count, production times, cost, and weight, addressing key challenges in agile New Space methodologies. Although PA6 CF falls short of PEEK in mechanical and thermal properties, its ease of processing and lower cost make it an attractive alternative for low-load applications. Pre-baking successfully mitigated outgassing, validating PA6 CF's potential for orbital environments. Enabling HPP into space can also allow low-energy recycling of the polymers.