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Multifunctional Composite Structures for Future Particle Accelerator Detectors

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Future particle accelerators present unique challenges for detector support structures, particularly in their innermost regions. These challenges require the development of novel structures with minimal mass, effective active cooling, high thermal conductivity, robust structural integrity, and shape stability under operational temperatures. Our research explores a novel design approach integrating printed preforms of continuous and discontinuous fiber composites using compression molding. We employed Polyphenylene Sulfide (PPS), reinforced with both pitch and pan based carbon fiber, due to its radiation tolerance. The design features a support structure incorporating a molded cooling channel, highly thermally conductive pitch-based carbon fibers to facilitate heat transfer from the detector to the cooling channel, and connections capable of withstanding high-pressure cooling fluids. This configuration leverages the advantages of 3D-printed discontinuous fiber (DF) preforms and continuous fiber (CF) layups consolidated through compression molding with highly tailored orientations. We conducted Finite Element Analysis (FEA) to investigate the thermal performance of the structure under typical operational loading conditions, as well as to assess thermal gradients across the prototype. Prototypes were manufactured and tested under similar thermal loading conditions used in the analysis. The test setup consisted of a surface heat source that provided a controlled heat flux on a region of the structure, internal forced convection through the cooling channel was provided with chilled water, and a thermal camera was used to monitor the temperature field on the surface of the structure. This testing regime provided a basis for comparative evaluation against state-of-the-art commercial carbon fiber (CF) prepregs and those specifically manufactured for this study. Preliminary results from pressure and thermal performance tests demonstrate the potential of this integrated approach for meeting the demanding requirements of high energy physics detectors.

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