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(HTCMC-S10-003-2026) Damage-tolerant design for impact resistant ceramic matrix composites

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This study investigates experimental methodologies for assessing impact tolerance and residual strength of ceramic matrix composites (CMC) thick drilled specimens taken from high-performance racing brake discs. The CMC is LSI C/SiC, with 3D long-fiber reinforcement in discs. A damage-tolerant approach was adopted, focusing on barely visible impact damage (BVID) and its effect on structural integrity. Low-velocity impact tests at varying energies identified visibility thresholds and damage mechanisms. Impact outcome showed repeatable damage modes and cracks shape. Post-impact evaluation employed a three-point bending test, proving the best compromise between simplicity and effectiveness. The effect of stress concentration of possible undesired anticlastic curvatures, typical of thick plates, and torsions were considered. These tests established relationships between impact energy, damage detectability, and residual strength. The results showed a relevant strength reduction (~30/40%) in specimens with hardly detectable damage. Fatigue tests under cyclic bending up to one million cycles on BVID specimen showed no stiffness loss or crack growth, confirming excellent fatigue resistance. The proposed methodologies provide a robust framework for defining BVID thresholds, assessing damage detectability, and establishing reliable design allowables for CMC components in safety-critical applications.

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(HTCMC-S10-004-2026) Hafnium-based ceramic nano composites: Near-zero ablation for hybrid rocket applications (Invited)

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In hybrid rocket systems, the nozzle—particularly the throat—is exposed to extreme heat flux and shear from combustion gases, making it highly prone to ablation in oxidizing environments. Such degradation can reduce chamber pressure and specific impulse, highlighting the need for refractory, oxidation-resistant nozzle materials. This study evaluates the ablation resistance of hafnium-based ceramic composites and their influence on chamber performance. Hafnium carbide (HfC) and hafnium diboride (HfB_2) generate stable refractory oxides that provide excellent protection. High-purity HfC–SiC and HfB_2–SiC composites with ultra-fine microstructures were tested using a 250 N hybrid thruster operating on high-test peroxide and HDPE. Inserts of HfC–SiC, HfB_2–SiC, and graphite were fired without cooling at ~30 bar for 25 s, and the HfB2–SiC insert underwent an additional 102 s of cumulative firing to assess reusable survivability. Both HfC–SiC and HfB_2–SiC showed near-zero erosion, with only minor throat shrinkage from oxide-induced volume expansion. In contrast, the graphite throat diameter increased by over 111%. Consequently, chamber pressure and specific impulse remained nearly unchanged with hafnium-based inserts, whereas the graphite nozzle saw drops of ~39% and ~5%. Hafnium-based composites therefore provide stable performance and exceptional ablation resistance for hybrid rocket nozzles.

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(HTCMC-S10-005-2026) Advanced manufacturing and densification techniques for fabricating ceramic matrix composites (Invited)

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Advanced/additive manufacturing (AM) techniques and densification processes relevant to fabricating ceramic matrix composites (CMCs) are surveyed. Current and potential future AM techniques are considered, including those applied to create both short and continuous fiber CMCs. Techniques to generate short fiber preforms, such as extrusion/direct ink write (DIW), binder jet (BJP), digital light processing (DLP) are elucidated. Advanced printing technologies that can create continuous fiber preforms are considered including desktop systems employing X-Y-Z gantry structures, filament winding and 3D robotic printing of continuous fiber and resin. The three primary net-shape densification processes will be reviewed, including reactive melt infiltration (RMI), polymer infiltration and pyrolysis (PIP), and chemical vapor infiltration (CVI), with advantages and disadvantages being discussed. Combining densification techniques will also be examined.

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(HTCMC-S10-006-2026) Polymeric ZrC precursors for ultrahigh-temperature ceramic matrix composites (Invited)

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Ultrahigh-temperature ceramic matrix composites (UHTC CMC) enable operations in the extreme conditions encountered by hypersonic vehicles, beyond what is achievable with C/C and C/SiC CMC. Leveraging progress with pre-ceramic polymer prepreg and polymer infiltration and pyrolysis (PIP)-based processing, General Atomics Electromagnetic Systems (GA-EMS) has developed a series of polymeric precursors for ZrC based UHTC CMC materials. A series of polymeric ZrC precursors have been produced, including soluble solids and low-viscosity liquids, to identify an optimal precursor that balances CMC performance and fabrication efficiency.

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(HTCMC-S10-007-2026) SiC-based matrix densification and high-temperature mechanical properties with solid-state synthesized additives for CMC: Boron and titanium

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SiC and SiC-based composites are prominent materials for harsh high-temperature environment applications, such as turbines and aerospace structures. Having a reliable structural material under these environmental conditions is crucial for system safety, performance, and efficiency. Over the past decade, SiC-based CMC has played a key role in commercial aviation engines and continues to expand its applications. However, significant efforts are being made to overcome inherent thermal limitations of commercialized SiC. Our group has been developing efficient strengthening techniques through factors related to filler compaction and precursor impregnation & pyrolysis (PIP), and has materialized high-strength carbon fiber-SiC CMC without additives (541 MPa in situ flexural strength at 2273K, inert). Moreover, we have been testing SiC filler for high-temperature atmospheric conditions with small amount of additives (usually below 1 vol.%), which result in beneficial behavior, strengthening while avoiding thermal degradation, and densification of the final product via solid-state processing. Additives containing boron (B) or titanium (Ti) have particularly caught our attention.