

reversible peak shift due to thermal expansion. These results provide new insight into diffusion mechanisms governing graphitization and highlight the importance of atomic mobility on carbon microstructure evolution.

2:20 PM

(HTCMC-S6-003-2026) Altering crystallite dimensions in benzoxazine derived carbon through iron catalyzed graphitization

T. Schneider¹; C. R. Dixon^{*1}; J. Wiggins²

1. University of Southern Mississippi, Polymer Science and Engineering, USA
2. University of Southern Mississippi College of Arts and Science, Polymer Science and Engineering, USA

Thermoset polymers are widely used as carbon precursors to generate carbon-rich solids upon pyrolysis at temperatures above 800 °C. However, carbon derived from traditional thermosets such as phenolics exhibit low thermomechanical performance compared to graphitizable precursors such as pitch. This limitation arises from the dense crosslinked networks inherent to thermosets which constrain molecular rearrangement during carbonization leading to a reduction in crystallite thickness (Lc) and lateral size (La). Recent studies in our labs have shown that the presence of iron catalysts significantly influence crystallite development in benzoxazine polymers. This presentation reviews our investigation of pyrolyzing high-char benzoxazine polymers (>60% at 1000 °C in N₂) with the incorporation of metallic particles leading to >4X increase in crystallite carbon size and significant improvement in carbon microstructure at 1000 °C. We will also review TGA-MS data showing changes in the degradation pathways associated with incorporation of iron catalysts and high-temperature X-ray diffraction (XRD) used to track the evolution of crystallite thickness (Lc) as a function of metal content and pyrolysis temperature.

2:40 PM

(HTCMC-S6-004-2026) Test and progressive failure analysis of a 2.5D carbon-carbon brake disk

G. J. Janszen^{*1}; A. Airolidi¹; E. Novembre¹; M. Gallo¹; R. Passoni²; A. Tasca²

1. Politecnico di Milano, Department of Aerospace Science and Technology, Italy
2. Brembo NV, Italy

Automotive brake disks for motorsport are among the most structurally demanding applications for carbon-carbon composites. The presence of notches and holes, and the combined torsional and bending loads during braking induce complex stress states that represent a challenge for the analysis of structural integrity. Moving from the characterization of a fabric reinforced 2.5D C/C laminate with tensile tests, the work presents the development and the calibration of an inelastic material model with damage variables associated with a multi-modal failure criterion, to be used within a Progressive Failure Analysis (PFA) approach. The response of a whole disk is experimentally assessed until failure by using a test bench, specifically designed to apply a quasi-static mechanical load system, equivalent to the one exerted during braking. A complete FE model of the test bench and of the C/C disk is developed and analyzed by applying the calibrated PFA approach. The results show an appreciable correlation with the experimental data, considering the torque at failure, the local strains measured by strain gauges applied on the disk faces, and the morphology of the final fracture at the end of the test. The numerical approach described can be considered a valuable tool to analyze the macroscopic response of C/C laminates and to provide reliable design indications.

HTCMCS6- Material, process development

Room: Pelican

Session Chair: Matthias Krodell, ECM - Engineered Ceramic Materials GmbH

3:20 PM

(HTCMC-S6-005-2026) Pathways to high-interlaminar shear strength carbon-carbon (Invited)

B. Goodman^{*1}

1. Goodman Technologies, LLC, USA

This study aims to develop innovative pathways for enhancing interlaminar shear strength in carbon-carbon (C/C) composites, addressing delamination challenges through AI-empowered additive and robotic manufacturing integrated with aligned nanoforest technologies. Methods encompassed collaborative scaling of AI-driven 3D printing for continuous fiber ceramic nanocomposites via automated robotic manufacturing systems, incorporating roll-to-roll prepreg production and fiber patch placement with Hi-Nicalon SiC reinforcements or Carbon fiber. Aligned carbon nanotube nanoforests were embedded using a nano-Velcro mechanism into prepregs, including the first nanoforesting of non-crimp 3D fabrics for Z-directional reinforcement. Melt-infiltrated ceramic matrix composites were advanced through partnerships. Arc-jet testing validated spacecraft thermal protection system designs. Results showed up to 118% gains in interlaminar shear strength and 120% improvements in Mode I fracture toughness. An 18-inch manufacturing coupon was demonstrated. These various super nanocomposites enabled reusable hot structures penetrating smoke and extreme environments. In conclusion, these pathways establish the world's first super nanocomposites for C/C, revolutionizing spacecraft thermal protection, hypersonic applications, and defense systems by reducing weight, costs, and sustainment demands.

3:50 PM

(HTCMC-S6-006-2026) Near-net shape Noobed 3D fabric pre-forms - Key to accelerate wider adoption of CMCs (Invited)

P. Khokar^{*1}; N. Khokar¹

1. Fureho AB, Sweden

Accelerating wider adoption of CMCs requires processing flexibility to efficiently convert brittle and expensive fibres like SiC, AlOx, quartz, and carbon pitch, which are available in relatively small volumes, into a variety of high-performing pre-forms. Traditional laminate pre-forms are prone to delamination. Weaving and braiding often damage these brittle fibres and cannot create complex near-net shapes required, e.g., for aircraft engine parts. Fureho's proprietary Noobing Technology uniquely overcomes these limitations by directly producing individual, near-net shape 3D fabric pre-forms, including double-curvature types. This process incorporates fibres in X-Y-Z directions without crimp. The Z-direction fibres provide high delamination resistance, significantly improving toughness and reliability. Unlike weaving or braiding, Noobing works on a unique 3D fabric-forming principle that significantly reduces setup and production times, and raw material requirements. This enables rapid prototyping and reduces wastage of expensive fibres, lowering both costs and environmental impact. The individual 3D fabric pre-forms are easy to handle for direct placement in mould/chamber, further streamlining CMC conversion. The consistent fibre arrangement across batches, results in a predictable performance and reduced frequency of quality testing, making CMCs economically and technically more attractive.