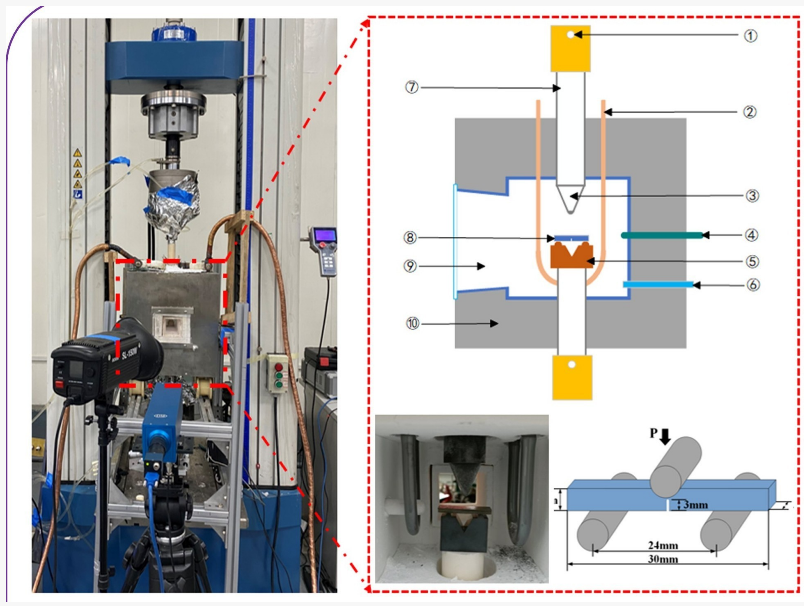
From Room Temperature to 1500°C: Unlocking the Toughness of Ceramic Matrix Composites Under Extreme Conditions

GA, UNITED STATES, June 3, 2026 /EINPresswire.com/ -- Silicon carbide fiber-reinforced silicon carbide (SiCf/SiC) composites are emerging as promising materials for the hottest parts of aircraft engines and hypersonic vehicles, where metals face increasing performance limits. A new study examines how temperature and surrounding atmosphere influence the fracture toughness and failure behavior of two-dimensional plain-woven SiCf/SiC composites. By combining high-temperature fracture tests, microscopic failure analysis, and physics-based modeling, the work reveals why these composites can resist sudden brittle fracture at room temperature, why their toughness declines at elevated temperatures, and how oxidation in air changes their damage pathway. The findings offer a practical basis for evaluating service safety and designing more reliable ceramic matrix composites for aerospace environments.



Tracking ceramic toughness under extreme heat. This graphical summary shows how two-dimensional plain-woven SiCf/SiC composites were tested and analyzed under high-temperature conditions. Using SENB tests, the team measured fracture toughness from room te

Thermal-structure materials used in aero-engines must retain strength, toughness, and damage tolerance under extreme heat, mechanical loading, and reactive environments. Ceramic matrix composites are attractive for their lightweight, heat resistant, and oxidation resistant, but their ceramic matrices remain intrinsically brittle. For silicon carbide fiber-reinforced silicon carbide (SiCf/SiC) composites, fracture toughness is a key measure of whether the material can slow crack growth instead of failing suddenly. Previous studies have explored mechanical properties, oxidation, interfaces, and damage evolution, yet systematic knowledge remains limited on how temperature and atmosphere jointly affect fracture toughness in two-dimensional plain-woven

SiCf/SiC composites. Based on these challenges, there is a need to carry out in-depth research on their high-temperature fracture mechanisms and predictive evaluation.

A collaborative research team from Northwestern Polytechnical University, the Aircraft Strength Research Institute of China, Chongqing University, and Beihang University published the study in Acta Mechanica Sinica. The work investigated the temperature- and atmosphere-dependent fracture toughness of two-dimensional plain-woven SiCf/SiC composites through single-edge notched three-point bending (SENB) tests, macro- and microstructural characterization, and a theoretical fracture toughness model designed for fiber-reinforced ceramic matrix composites.

The team tested the composites from room temperature to 1500 °C in both argon and air environments. At room temperature, the fracture toughness reached 47.7 MPa m1/2, higher than many previously reported values for similar SiCf/SiC composites. As temperature increased, toughness gradually declined in both atmospheres. In argon, the values dropped from 42.3 MPa m1/2 at 800 °C to 23.9 MPa m1/2 at 1350 °C. In air, oxidation accelerated performance loss, with fracture toughness falling to 34.5 MPa m1/2 at 800 °C, 28.9 MPa m1/2 at 1000 °C, and 21.1 MPa m1/2 at 1200 °C. A surprising twist: the air□argon gap narrows at ultra□high temperatures. The difference between air and argon first increased and then narrowed at higher temperatures. The team attributes this to silicon dioxide (SiO□) oxidation products, which partially block oxygen□entry channels and contribute to crack healing – a self□healing effect that partly offsets oxidation damage under extreme heat. Microscopy showed that crack deflection, interface debonding, and fiber pull-out were central toughening mechanisms. However, as temperature rose, fiber pull-out shortened and oxidation strengthened fiber-matrix bonding, making the material more brittle, especially in air. The proposed model incorporated matrix toughness, plastic work, fiber pull-out, and residual thermal stress. It successfully matches both the team's experimental data and published results for a wide range of fiber□reinforced ceramic matrix composites, offering a robust theoretical tool for future material design.

The authors said the study helps translate complex high-temperature damage processes into clearer design guidance for ceramic matrix composites. Their key message: fracture toughness is not controlled by temperature alone. Instead, atmosphere, oxidation, interface behavior, fiber pull-out, and residual thermal stress act together to determine whether the composite fails gradually or turns brittle. By linking experiments with a physics-based model, the work provides a practical way to estimate high-temperature toughness using material parameters that can often be obtained from existing data. This makes the model useful for early material screening and performance evaluation.

These findings have direct implications for aerospace thermal-structure components that must survive demanding service environments- including engine hot-end structures, thermal protection systems, and hypersonic vehicle components. Reliable prediction of fracture toughness can support safer material selection, lifetime assessment, and structural design. The model also highlights practical routes for improving performance, such as optimizing matrix modulus, fiber properties, interfacial shear strength, and oxidation resistance. Although the current model does not yet fully capture oxidation effects in air, the experimental results show where future modeling should move next. By clarifying both the benefits and vulnerabilities of SiCf/SiC composites, the study supports their broader use in high-temperature aerospace applications.

References
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Lucy Wang
BioDesign Research
email us here
