

HTCMC5 Abstract

Creep and Stress-Strain Behavior after Creep for SiC fiber reinforced, Melt-infiltrated SiC Matrix Composites

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Silicon carbide fiber (Hi-Nicalon Type S, Nippon Carbon) reinforced silicon carbide matrix composites containing melt-infiltrated Si were subjected to creep at 1315°C for a number of different stress conditions. This study is aimed at understanding the time-dependent creep behavior of CMCs for desired use-conditions, and also more importantly, how the stress-strain response changes as a result of the time-temperature-stress history of the crept material. For the specimens that did not rupture, fast fracture experiments were performed at 1315°C or at room temperature immediately following tensile creep. In many cases, the stress-strain response and the resulting matrix cracking stress of the composite change due to stress-redistribution between composite constituents during tensile creep. The paper will discuss these results and its implications on applications of these materials for turbine engine components.

CREEP AND STRESS-STRAIN BEHAVIOR AFTER CREEP FOR SIC FIBER REINFORCED, MELT-INFILTRATED SIC MATRIX COMPOSITES

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Work supported by a joint NASA, Goodrich Space Act Agreement

Objective

- To determine the creep behavior of the Hi-Nicalon Type S*, slurry-cast melt-infiltrated (MI) composite system including the retained stress-strain behavior after prolonged tensile creep
 - History dependent σ/ϵ for modeling purposes
 - Creep-induced matrix compression to raise “proportional limit” stress [1,2]

* Nippon Carbon Co., Japan

Hi-Nicalon Type S, Melt-Infiltrated Composite System

- A very creep resistant and relatively strong fiber
- A relatively high matrix cracking matrix stress composite
 - Slurry SiC + melt Si fills in most of open porosity remaining after CVI SiC
 - Removes (fills in) stress concentrators present in CVI SiC matrix systems
 - Adds compressive stress to matrix due to volume expansion of Si on cooling and thermal expansion difference between Si ($\sim 3 \times 10^{-6} / ^\circ\text{C}$) and SiC ($\sim 4.5 \times 10^{-6} / ^\circ\text{C}$)

Experimental: Composite Processing

- Composite processing consisted of the following steps:
 - Stacking and BN CVI (interphase) of eight plies of woven fabric
 - SiC CVI in order to rigidize the preform and protect the fibers from melt-infiltration
 - Slurry-infiltration of SiC particles
 - Melt-infiltration of molten Si
- Two different matrix compositions were processed [3]:
 - High CVI SiC & low Si content (A Panels)
 - Low CVI SiC & high Si content (B Panel)

Experimental: Mechanical Behavior

- Tensile tests were performed on 152 mm long dogbone specimens (12.6 mm in grip and 10 mm in gage)
- Unload, reload tensile hysteresis tests were performed at room temperature to determine the residual stress in the matrix
- Elevated temperature tests were loaded monotonically (0.25 mm/min) to failure for fast fracture or to the predetermined load for tensile creep
- If tensile creep survived 100 hours, the specimen was unloaded to zero stress and either reloaded immediately to failure at 1315°C or cooled to room temperature and tensile hysteresis to failure was performed
- Elastic modulus was determined from linear regression of the 5 to 50 MPa portion of initial loading of σ/ϵ curve.
- The 0.002% offset stress was used to characterize non-linearity (proportional limit)

Figure 1: Tensile Creep Curves

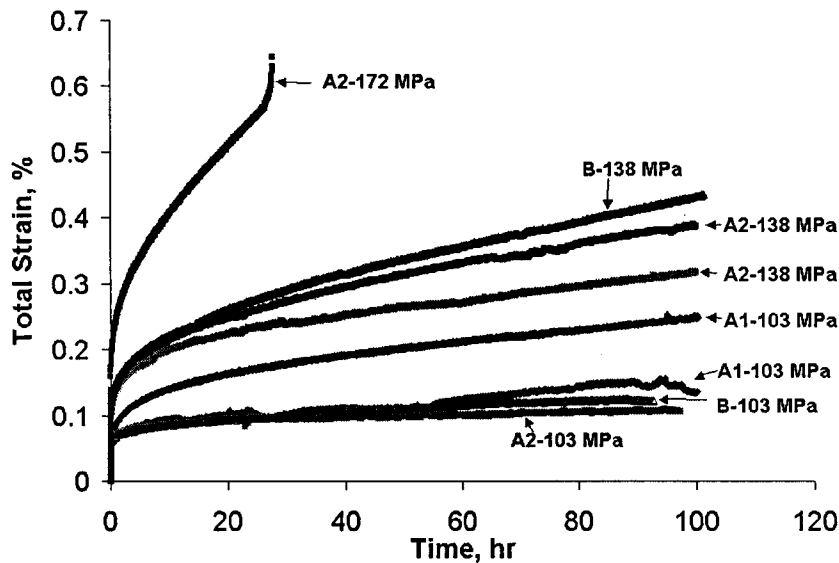


Figure 2: Strain Rate vs. Time

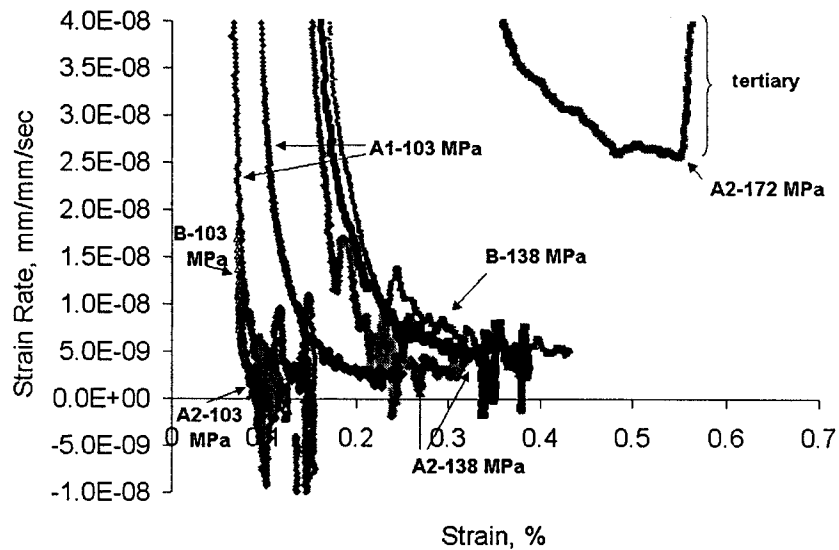


Table I: Tensile Data

Panel	Experiment	Creep Stress, MPa	E(RT), GPa	E(1315) Initial Loading, GPa	E(1315) After Creep, GPa	E(RT) after creep	Minimum Strain Rate, sec ⁻¹	Creep Strain, %	Ult. Stress, MPa
A1	RT		262						349
	1315FF								253 ^x
	1315Ccreep	103		NA	209		2.80E-09	0.18	256*
	1315Ccreep	103		223	209		2.50E-09	0.09	267*
A2	RT		220						412
	1315FF			182					271 ^x
	1315Ccreep	103		225	198		2.80E-10	0.05	295*
	1315Ccreep	138		184	157		3.90E-09	0.3	291*
	1315Ccreep	138		203		233	3.10E-09	0.23	321 ^R
	1315Ccreep	172		177			2.60E-08	0.44 ^a	
B	RT		270						362
	1315Ccreep	103		217	208		5.60E-10	0.07	255*
	1315Ccreep	138	263	213			5.20E-09	0.36	

* Tested at 1315°C; ^x Did not fail in hot zone; ^a Prior to the onset of tertiary creep

FF = fast fracture;

R = tested at room temperature

Results

- Creep failure within 100 hours only occurred for the 172 MPa condition
- Primary creep dominated the creep-time curves (**Figures 1 and 2**). Perhaps a steady-state was reached for the 138 MPa creep condition.
- Retained strength after 100 hour creep was essentially equal to or greater than the 1315°C fast-fracture strength, even for specimens that exhibited 0.3% time-dependent strain. Although, fast-fracture of as-produced specimens never failed in hot zone for 1315°C testing whereas fast-fracture after creep usually did.

Figure 3: Stress-Strain History for Panel A2

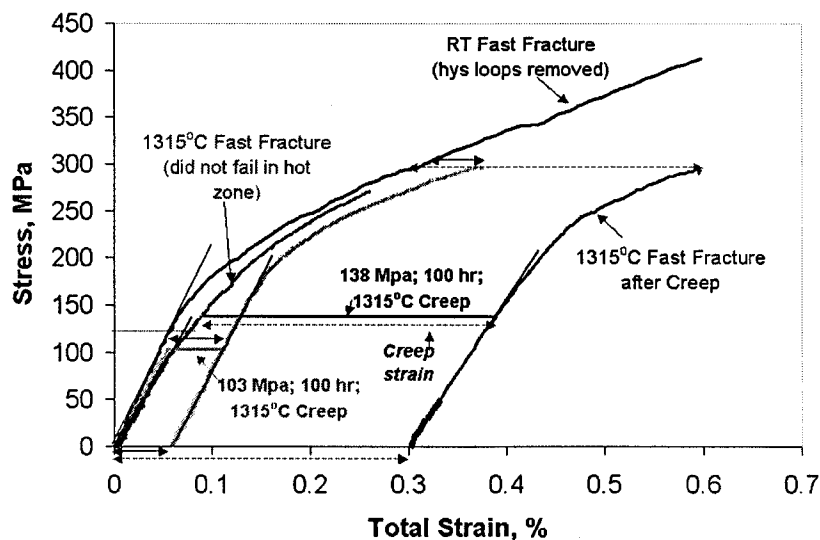
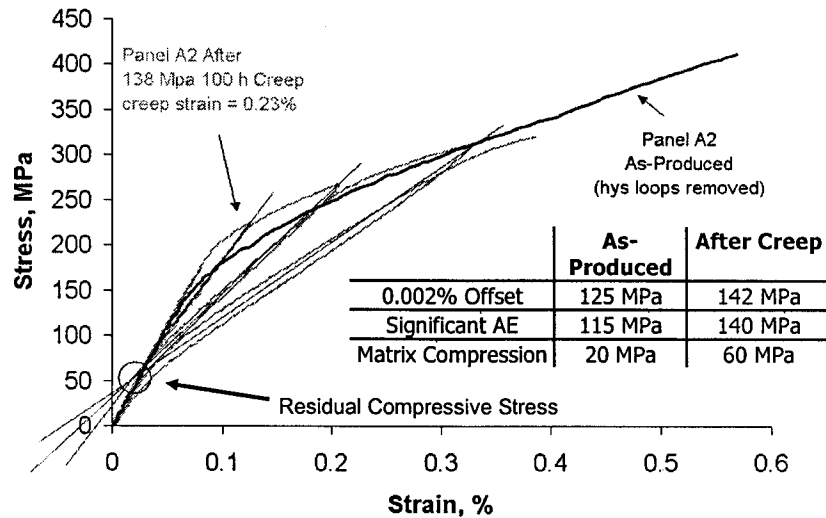


Table II: Offset Stress

Panel	Experiment	Creep Stress, MPa	0.002% offset stress	
			1315C Initial Loading, MPa	1315C After Creep, MPa
A1	1315FF	--	70	
	1315Ccreep	103	NA	127
	1315Ccreep	103	82	147
A2	1315FF	--	103	
	1315Ccreep	103	67	166
	1315Ccreep	138	88	159
	1315Ccreep	138	79	
	1315Ccreep	172	85	
B	1315Ccreep	103	95	112
	1315Ccreep	138	90	

- There is considerable non-linearity in 1315°C loading curve at relatively low stress (> 100 MPa) for the applied loading rate (see **Table II**). This is believed to be due primarily to creep during loading and not matrix cracking due to the absence of significant matrix crack formation (below).
- After tensile creep, reloading specimens resulted in a lower E; however, the “offset stress” was significantly increased (**Table II**), especially for A panels with the greater CVI SiC content.
- The time-dependent creep strain was essentially identical with the permanent strain measured after unloading from the creep condition and the difference in strain from after-creep fast-fracture and as-produced fast-fracture (see double-sided arrows in **Figure 3**).

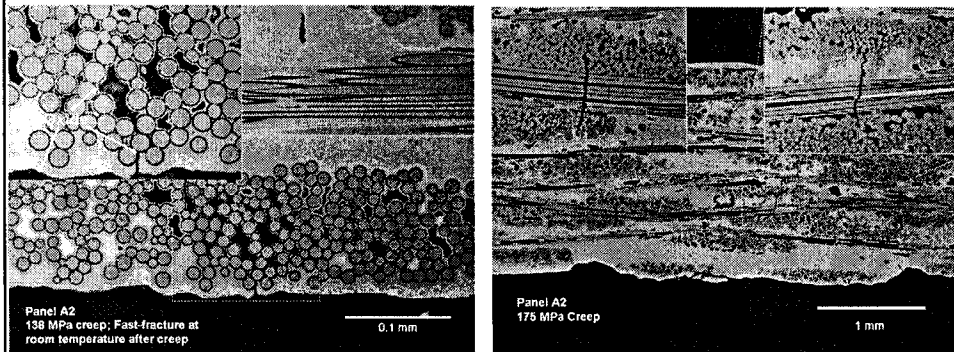
Figure 4: Room-temperature tensile after creep (panel A2)



- Room temperature tensile behavior of after-creep specimen (**Figure 4**) exhibited all the qualities of increased compression in the matrix: higher “proportional limit” stress, higher AE activity stress, and higher residual compressive stress [4].
- Note that very little matrix cracking occurred during creep. For 103 MPa crept specimens, no creep-induced* matrix cracking could be discerned. For 138 MPa crept specimens, a few surface creep-induced microcracks were observed (**Figure 5a**). For the 172 MPa crept specimen, six periodic (spaced ~ 2 mm apart) internal microcracks were observed that resided in the same longitudinal tow three plies from the surface (**Figure 5b**). Several of these caused fiber failure; however, the matrix cracking seemed to not extend beyond the neighboring plies.

* Creep-induced cracking was easy to distinguish from matrix cracking caused during fast fracture. Matrix cracking due to fast-fracture was difficult if not impossible to observe without the aid of plasma etching. Creep-induced matrix cracking exhibited significant opening and oxidation for surface-exposed cracks.

Figure 5: Micrographs of crept specimens.



a. Surface microcrack in 138 MPa crept specimen.

b. Internal unbridged microcracks in 172 MPa crept specimen.

Summary and Conclusions

- Woven Hi-Nicalon Type S MI composites exhibit excellent creep resistance at 1315°C and excellent retained properties after 100 hour creep for applied creep stresses up to 138 MPa.
- Tensile creep induced compression in the matrix, presumably due to the relaxation of the MI portion of the matrix which resulted in a higher matrix cracking stress composite.
- It may be possible to take advantage of this creep-induced phenomena for certain high stress applications, e.g., a turbine blade.

References

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