Low Creep/Low Relaxation Thermoplastic Polymer Composites for Deployable Structures

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Problem

Key Term – Stress Relaxation: the time-dependent decrease in stress of a viscoelastic material held under constant strain

- Deployable structures spend up to one or two years in stowage before deployment
  - Can result in loss of structural integrity if significant relaxation occurs
- Need to mitigate stress relaxation within ultralightweight carbon fiber / polymer composites
- Current investigations in thermosets have yielded significant progress for BMI matrices

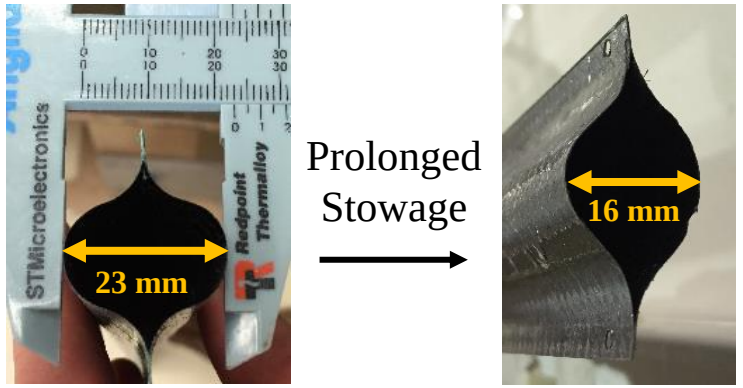


Fig. 1. About 50% loss in buckling strength due to stress relaxation [1]. Image credit: NASA

Objective

Driving Question: What progress can be made in reducing the relaxation modulus of carbon fiber / polymer composites?

- Investigate thermoplastics for use as a matrix material in low-relaxation carbon fiber composites
- Characterize Polyether-Ether-Ketone (PEEK) to fabricate samples of CF/PEEK composites
  - Benefits of PEEK
    - One-step cure process
    - Out-of-autoclave
    - Reusability
    - Strong fiber-matrix interface adhesion

Approach

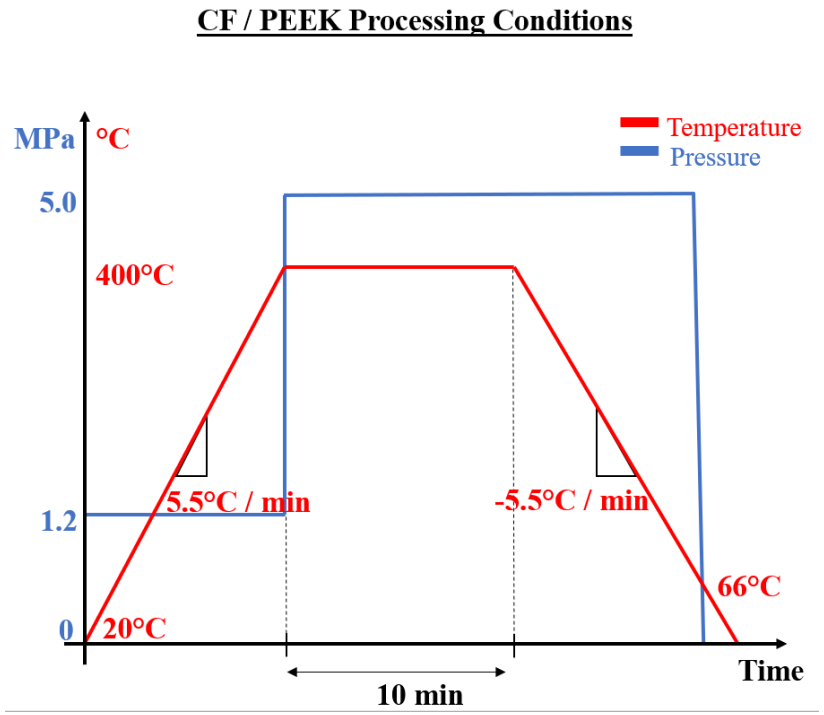


Fig. 2. Process conditions for CF/PEEK sample fabrication

- Processing conditions
  - Apply pre-holding pressure of 1.2MPa
  - Heat layup to 400°C @ about 5.5°C/min
  - Apply 5MPa at temp 400°C
  - Hold 10 min
  - Decrease temp @ about -5.5°C/min
  - Release pressure when layup temp < 66°C

- Layup
  - Three layers polyimide release film bookends sample
  - 1.5” X 2.5” mold
  - 4 layers
  - CF to PEEK ratio / layer
    - CF: 1 ply CF weave @ 62 gsm
    - PEEK: 4 plies PEEK foil @ 8µm thick / ply

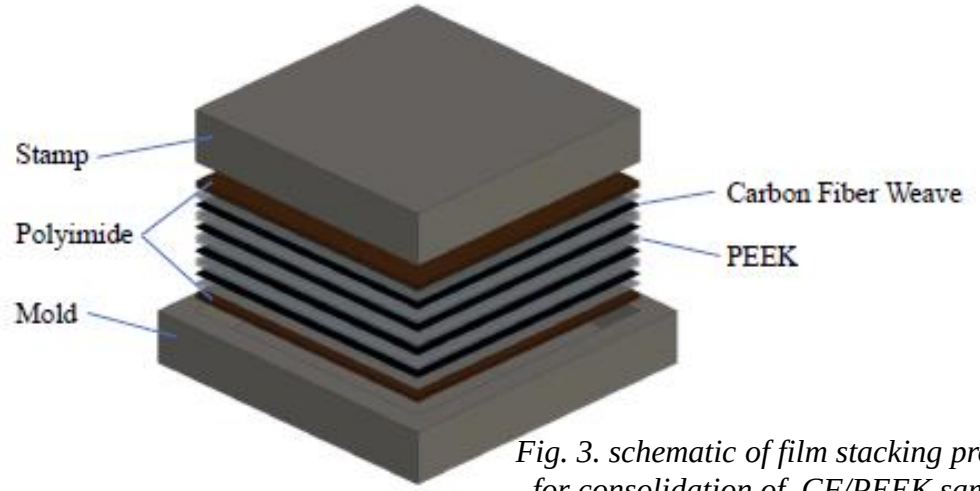


Fig. 3. schematic of film stacking process for consolidation of CF/PEEK sample (not to scale)

Results

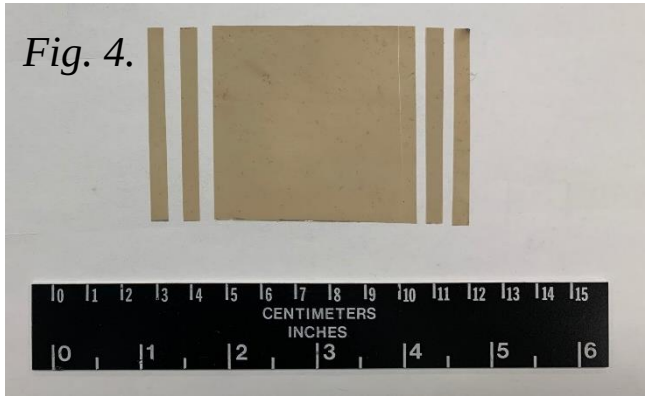


Fig. 4. KH 00280-31-1

PEEK Pristine

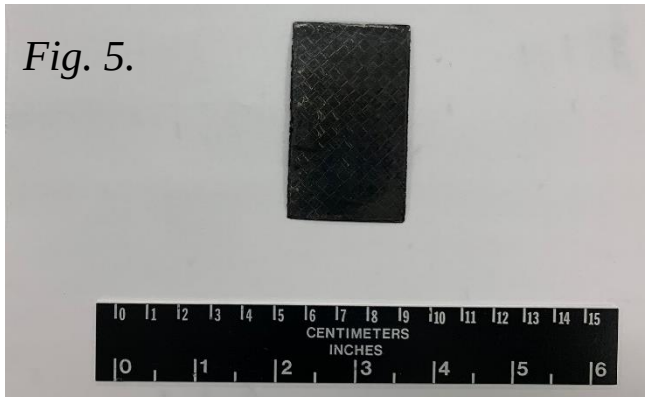
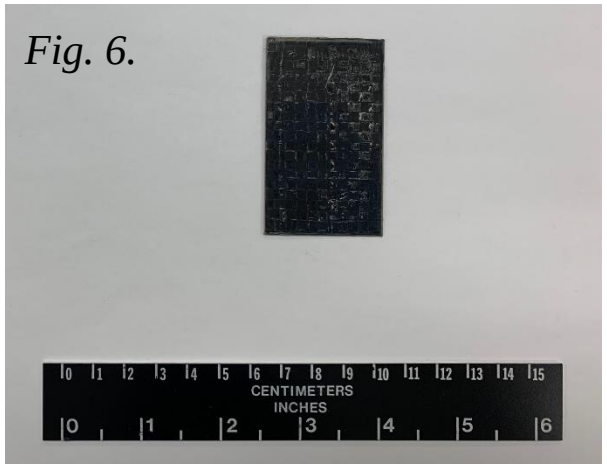


Fig. 5. KH 00280-32-1

CF/PEEK $[\pm 45\ PW]_4$

KH 00280-33-1

CF/PEEK $[\pm 45\ PW_2/0\text{-}90\ PW_2]$ *Fig. 6.*



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CF/PEEK $[0\text{-}90\ PW]_4$ *Fig. 7.*

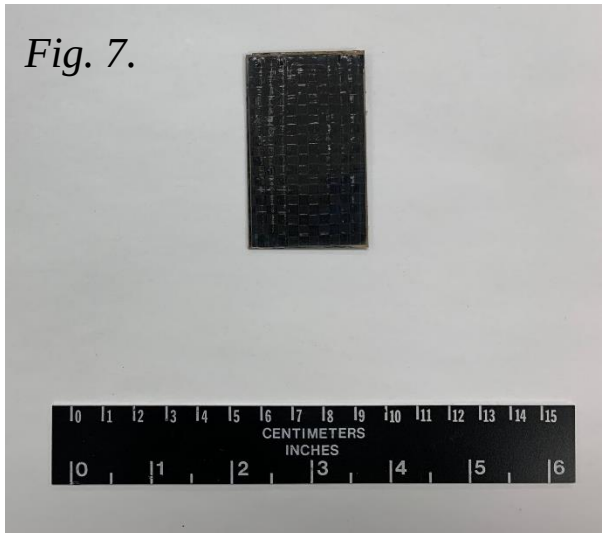

Fig. 4 – 7. Successfully fabricated samples of PEEK Pristine, CF/PEEK $[\pm 45\ PW]_4$, CF/PEEK $[\pm 45\ PW_2\ /0\text{-}90\ PW_2]$, CF/PEEK $[0\text{-}90\ PW]_4$, respectively

Analysis

Table 1. Carbon Fiber Mass Fractions

Sample	Mass [g]	CF m_f
$[\pm 45\ PW]_4$	0.9330	**64.3%**
$[0\text{-}90\ PW]_4$	0.9116	**65.8%**
$[\pm 45\ PW_2/0\text{-}90\ PW_2]$	0.8999	**66.7%**

$$m_f = \frac{[\rho_A * A * n]_{CF}}{m_s}$$

m_f = mass fraction
ρ_A = areal density
A = area
n = number of layers
m_s = total post-fabrication mass of sample

- Typical CF mass fraction: 60% - 70%
- Suggests low void content
- Low void content tends to improve fiber-matrix interface adhesion
  - Need SEM & acid digestion for confirmation
- All results are as expected

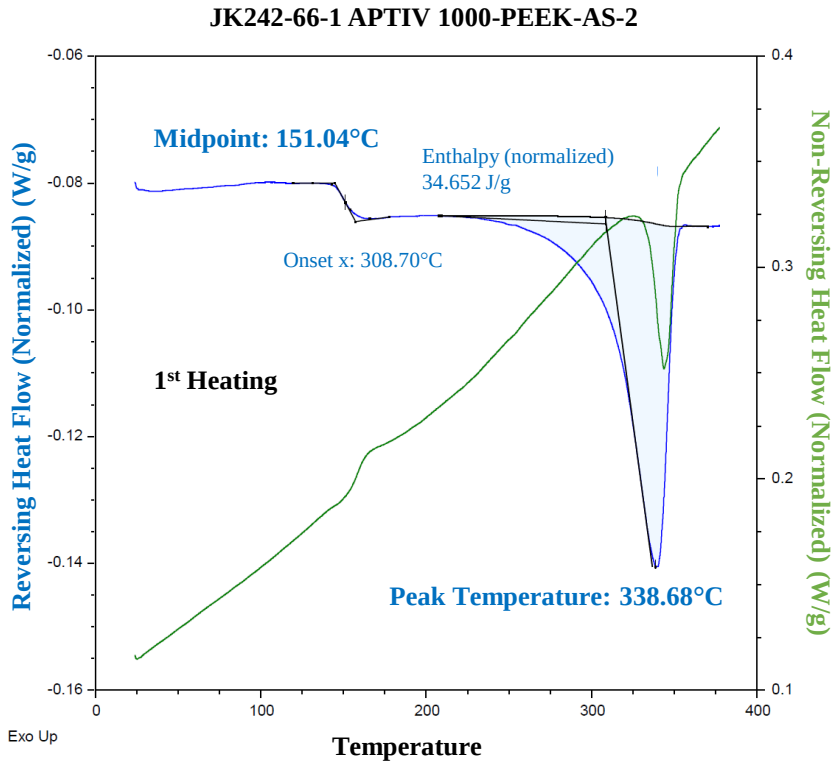

Fig. 8. DSC thermogram of PEEK

- Differential Scanning Calorimeter (DSC) data shows a glass transition temperature of 151°C and a melting onset temperature of 309°C.
  - Upper limit of application temperature for CF/PEEK composites

Summary

- Easy one-step cure process
  - Total process takes ~6 hrs to complete
- 4 CF/PEEK composite samples were fabricated successfully in unique ply orientations for deployable structures
- All mass fractions were within typical ranges for carbon fiber polymer composites
- SEM data is needed to verify void content and completeness of individual fiber coatings

Next Steps

- COVID-19 impacted research efforts at week 8 of investigation
  - ~3 weeks in-lab time required for relaxation testing on DMA
- Fabrication of subscale demonstration specimens
  - Long term TRAC boom stowage test comparing reduction in creep/stress relaxation for BMI thermoset and PEEK thermoplastic

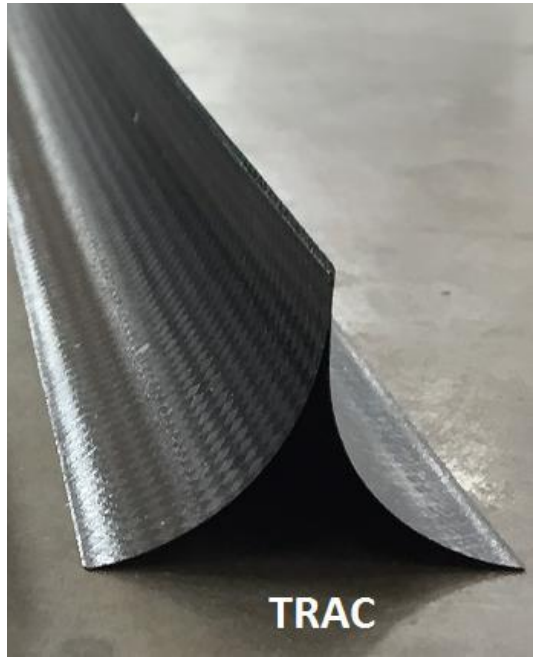

Fig. 8. Future work of comparing the relaxation in Triangular Rollable And Collapsible (TRAC) booms between CF/PEEK and CF/BMI composites illustrated [1]. Image credit: NASA

Acknowledgements

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Figure References:

[1] J. M. Fernandez et al., "An Advanced Composites-Based Solar Sail System for Interplanetary Small Satellite Missions," in 2018 AIAA Spacecraft Structures Conference, Kissimmee, Florida, 2018, doi: 10.2514/6.2018-1437.