Deformation and Fracture Experiments on Advanced Aerospace Materials

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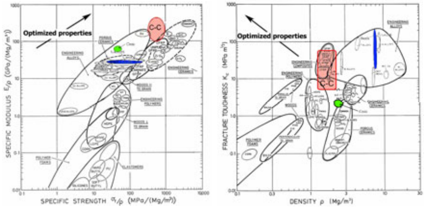
ABSTRACT

- Advanced aerospace materials continue to be developed in order to address the continuing need for materials with high specific strength and stiffness.
- Materials properties of interest include strength, toughness, high cycle fatigue, and fatigue crack growth, among other important considerations.
- In this work, the Center for Mechanical Characterization of Materials at CWRU and the unique equipment housed therein is being utilized to mechanically evaluate both conventional and advanced aerospace materials.
- High strength 4340 steel, carbon-carbon composite, and Carbon-Silicon Carbide composite were tested to examine their relative properties.
- Ashby Plots show properties of various classes of materials, including tested materials.



MATERIALS AND DESIRED DATA

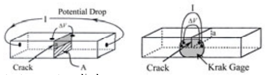
Carbon-Carbon Composites(T300 & SWB): Crush Resistance, Bend Strength, Toughness, High Cycle Fatigue, Fatigue Crack Growth

4340 Steel: Strength, Fatigue, Fatigue Crack Growth

C/SiC Composite (Cesic®): Toughness, Fatigue Crack Growth

MECHANICAL TESTING

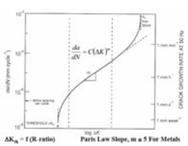
- The following ASTM standards were used to guide testing
  - ASTM E-8 Tension Testing
  - ASTM E-399 Fracture Toughness Testing
  - ASTM E-647 Fatigue Crack Growth Testing
  - ASTM E-647 Annex Potential Drop Measurement of Crack Growth
- Crack growth monitoring for Toughness/Fatigue



- Constant current applied
  - Using Potential Drop, Sample conducts the current
  - Using Krak Gage, bonded surface foil conducts the current
- Resistance (voltage measured)=f(crack length)
  - Monitor during testing to determine crack growth under quasi-static and cyclic loading
  - Using Potential Drop, Resistance of sample measured
  - Using Krak Gage, bonded surface foil's resistance is measured

TYPICAL FATIGUE CRACK GROWTH DATA

- Need fatigue crack threshold (ΔK_{TH}), Paris Law slope (m)



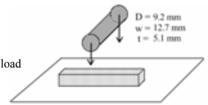
CARBON-CARBON COMPOSITE

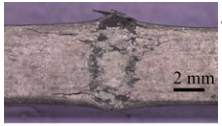
ALLCOMP Carbon-Carbon Composite

- C-C supplied in two forms
  - T300: C-C composite containing continuous PAN T300 fibers
  - SWB: Chopped Fiber Composite containing SWB fibers

Crush Resistance:

- C-C composites may damage due to crushing
- Crushing may influence bend/toughness results
- Crush tests conducted to determine critical crushing load
  - •Ball Bearing, D=22.2 mm
  - •Roller, D=9.6 mm





Crush Load	T300	SWB
Ball Bearing	1.0-1.2 kN	2.1 kN
Roller	1.8 kN	2.7 kN

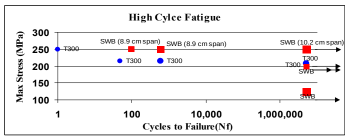
Bend Strength:

	T-300	SWB
3 Point Bending	218 MPa	260 MPa

- Displacement Rate = 0.25 mm/min
- Roller Diameter = 9.6 mm
- 10.2 cm span (to avoid crushing)

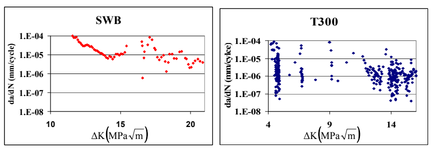
High Cycle Fatigue:

- 3 Point Bending
- Frequency = 10-20 Hz
- Load Ratio, R = 0.1, 0.4, 0.47, 0.5
- Spans varied to avoid premature failure due to crushing
- Survived high cycle fatigue at a high fraction of bend strength
- Arrows indicate sample did not fail
- Crushing observed at spans <10.2 cm , fatigue life reduced



Fatigue Crack Growth (da/dN vs ΔK) of ALLCOMP C-C Composite:

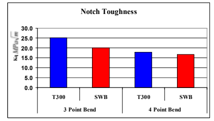
- 3 Point Bending
- Frequency of 4 -10 Hz depending on span length
- Krak Gage used to measure crack growth
- Load Ratio, R=0.1

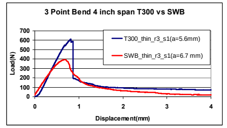


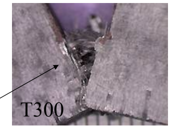
- SWB and T300 fatigue crack growth behavior unlike metals
  - No unique ΔKth
  - Crack Arrest/Retardation as ΔK increased
    - •Possibly due to crack bridging and damage zone development

Notch Toughness of C-C composites:

- •3 and 4 Point Bending
- •Displacement Rate= 0.25 mm/min
- •Notch = .25 mm radius
- •Toughness at max load
  - •T300>SWB
- •Toughness (Area under the curve)
  - •T300 > SWB







- •Non-Catastrophic Fracture
  - •R-curve Behavior
  - •Source(s) of R curve behavior
    - Bridging of crack with Carbon fibers

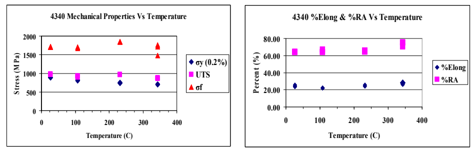
4340 STEEL

Heat Treatment Conditions:

- •Austenitized, Quenched, and Tempered

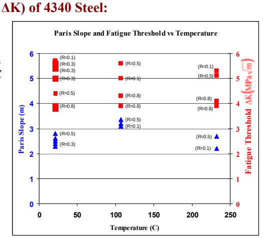
Tension Testing:

- •Cylindrical Tension Samples
- •Test Temperatures: 70°F, 225°F, 450°F, 650°F
- •Strain Rate: 0.001 / sec
- •Properties Measured: σ_y, UTS, σ_f, % elongation, % Reduction in Area



Fatigue Crack Growth(da/dN vs ΔK) of 4340 Steel:

- •Typical da/dN vs ΔK for metal
- •Frequency = 20 Hz
- •Potential Drop measures crack growth
- •Test Temperatures: RT, 107°C, 232°C
- •Load Ratio, R: 0.1, 0.3, 0.5, 0.8



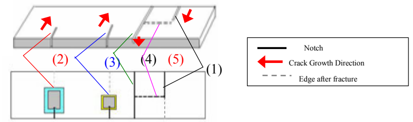
Fracture Toughness :

- •Fatigue pre-cracked
- •Crack growth monitored with Potential Drop

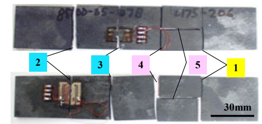
Conditions	Fracture Toughness
RT	127 MPa √m (R-curve)
107°C	89 MPa √m (R-curve)
232°C	109 MPa √m (R-curve)

C/SiC COMPOSITE (CESIC®)

Schematic of Tests:



Sample Appearance:



Notch Toughness:

- 3 Point or 4 Point bending
- Notch Radius = 0.25 mm

Sample #	Conditions	$K_q (MPa\sqrt{m})$
1	Notched toughness (a/w=0.5)	1.9
2	K-gage, 25μm crack growth	3.1
3	K-gage, No crack growth	4.2
4 (Transverse)	Notched toughness (a/w=0.5)	2.8
5 (Longitudinal)	Notched toughness (a/w=0.43)	2.9

Fatigue Crack Growth (da/dN vs ΔK):

- 3 Point or 4 Point bending
- Notch Radius = 0.25 mm
- Frequency = 20 Hz
- Krak Gage measured crack growth (da/dN)
  - Paris Slope m > 60
  - ΔK_{th} < 1.5 MPa √m

CONCLUSIONS

- Mechanical Properties Measured on:
  - ALLCOMP C-C Composite
  - 4340 Steel
  - C-SiC Composite
- Properties Measured Include:
  - Crush Resistance (ALLCOMP C-C)
  - Strength (ALLCOMP C-C, 4340)
  - Toughness (ALLCOMP C-C, 4340, C-SiC)
  - High-Cycle Fatigue (ALLCOMP C-C)
  - Fatigue Crack Growth (ALLCOMP C-C, 4340, C-SiC)
- Crack monitoring successfully conducted via
  - Potential Drop (PD)
  - KRAK™ Gages
- Significantly different behavior exhibited

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